ROOFING – AN INVESTIGATION, AND RECOMMENDATIONS FOR IMPROVING PERFORMANCE ON ALBERTA GOVERNMENT BUILDINGS

Department of Public Works
Government of the Province of Alberta
August, 1967.

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MEMORANDUM OF TRANSMITTAL

FROM : E. C. Luck, P. Eng.
Bryan Campbell-Hope, M.R.A.I.C.

TO: J. F. Hunt, P. Eng.
Director of Design and Construction
Department of Public Works

RE: Roofing

We are herewith submitting a report entitled "Roofing - An Investigation, and Recommendations for Improving Performance on Alberta Government Buildings".

We believe this report will contribute to the understanding of roofing failures in Alberta, and will assist designers and builders in understanding the importance of good practice in roofing.

Work was begun on this project in March, 1967 with preliminary inquiries being made into the locations of roofing failures. Subsequently, interviews were conducted with Architects, General Contractors, Roofing Contractors, material suppliers and manufacturers, and with individuals carrying out research regarding roofing and thermal insulation. These interviews were conducted until June of 1967. Upon the conclusion of interviews, all information gathered was reviewed and this report was prepared.

We believe that this report will help in clarifying the role of

[illegible]

FROM : [illegible]

Acting Commanding Officer, [illegible]

TO : [illegible]
Director of [illegible] and Construction
Department of [illegible]

[illegible]

We are herewith submitting a report entitled "Heating - An investigation, and recommendations for changes in [illegible] Government Buildings".

We believe this report will contribute to the [illegible] of heating [illegible] in [illegible], and will assist [illegible] and [illegible] in understanding the importance of good [illegible] in heating.

Work was begun on this project in March, 1955 with preliminary [illegible] being made into the [illegible] of heating [illegible]. [illegible] generally, [illegible] were [illegible] with [illegible], [illegible] [illegible] heating [illegible], [illegible] and [illegible] of [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] project.

We believe that this report [illegible] [illegible] [illegible] the [illegible] of

the manufacturer, designer and builder with regard to built-up roofs, and what must be done to improve the performance of built-up roofs.

In accordance with the terms of reference outlined to us, we include in this report specific recommendations as to which products should be used in the construction of roofs for the Department of Public Works.

Respectfully submitted,

Bryan Campbell-Hope, M.R.A.I.C.

E. C. Luck, P. Eng.

cc: H. H. Neelands, Chief Engineer

N. F. Fleming, Chief Architect

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SYNOPSIS

Following the popularization of flat roofs in North America, and the attending relocation of insulation from above the ceiling to above the roof deck, there has been a significant increase in roofing failures.

Failures of bituminous built-up roofs can be attributed to two principle factors, these being faulty design and faulty workmanship. Faulty design can be overcome if designers have a proper understanding of building science and recognize factors which affect the performance of a building and its roof system. Faulty workmanship can be overcome through a comprehensive program of education and training for those in the roofing trade.

With the rapid development of many new products for use in the construction of built-up roofs, the designers must rely more and more on manufacturers' recommendations; the designer no longer can assess, in many instances, the performance of a product or system based on his experience. A tendency exists today for designers to overlook the limitations of the materials they specify, and to think of a material as being either good or bad, depending on their very often limited experience with the material.

The principal function of the roof of a building is the protection of the building itself, and its contents, from the elements. In order that a roof perform effectively for its expected service life, certain basic features of design should be adhered to. These features include sloping of the roof and flashing surfaces to permit positive drainage, application of sufficient asphalt of adequately high softening point to maintain the built-up roof membrane watertight, the application of flashings to protect certain areas of roof membrane rather than to replace the membrane, the control of air and moisture losses from the building into the built-up roof, and proper allowance for building movements.

It is doubtful if roofing performance will improve unless present roofing practise and design are improved through a greater appreciation of the basic principles involved.

I INTRODUCTION

(a) Authority for Investigation and Report

In a memorandum dated February 16, 1967, Mr. H. H. Neelands, P. Eng., Chief Engineer for the Alberta Government Department of Public Works, requested that Mr. E. Luck and Mr. B. Campbell-Hope conduct an investigation into roofing problems. Mr. J. F. Hunt, Director of Design and Construction for the Department, had on February 9, 1967 outlined the general terms of reference to govern this investigation, and these terms of reference were forwarded to the writers by the Chief Engineer.

Mr. Hunt, in his memo of February 9th, stated, "I would like the report to make recommendations as to which products should be used for the Department of Public Works' roofs. The investigating team should then be prepared to set forth specifications on how to apply the various products they would recommend for our use".

This report is presented, not only in a manner whereby non-technical laymen might gain some insight into roofing and its associated problems, but also in a manner whereby (it is hoped) technical men will understand the reasons for the recommendations made.

(b) Aim of Report

This report has been produced in an effort to assist the Government of Alberta, Department of Public Works, in bettering the quality of roofing for Government buildings. The objective, simply stated, is to reduce the incidence of roofing failures on Government buildings.

Failure, as applied to a built-up roof, can be considered in basically two ways. A roof can be said to have failed if it allows water to enter the building it is protecting. This type of failure might damage the building and its contents appreciably, but the damage to the roof itself may be small. The other type of failure is one in which either the roof membrane or insulation has become severely deteriorated but no water has as yet leaked into the building. A severely blistered membrane is not considered a failure. It has not failed until it allows water to pass through it.

The terms "roofing", built-up roof" and "roofing sandwich", as used in this report include vapour barrier, insulation and membrane. The structural roof or roof deck will be referred to as such.

Very little, if any, of the information and recommendations contained in this report are new. What is presented is basically no more than a reiteration of facts and opinions compiled by researchers and practical men over a period of many years.

It is not the intent of the writers to present a design manual type of report; such reports have been published literally by the hundreds. Many books have been written on the subjects of roofing materials, roofing design and roofing failures. This report has been prepared primarily from information gathered firsthand from personal observation and discussion.

The opinions expressed in this report are those of the writers, unless otherwise noted.

(c) Approach to Investigation

In order to get as broad a view as possible regarding roofs and roofing, the writers interviewed representatives of the following trades, professions and organizations:

General Contractors
Private Architects
National Research Council, D.B.R.
Alberta Research Council
Insulation Manufacturers
Roof Felt Manufacturers
Asphalt Producers
Roofing Contractors - (Firm principals and foremen)
Sheet Metal Contractors
Building Inspectors
Roofing Contractors Association

Interviews were conducted principally at places of business, factories and jobsites.

The writers inspected several roofing failures, and visited numerous projects when the roofing was being installed.

A considerable number of publications, dealing with roofing failures, were studied. The study of the writings of others was done in the main, only after the writers had formulated their own opinions, based on personal interviews and inspections. In this way, a comparison was obtained between the writers' viewpoints and conclusions based on firsthand experience, and the viewpoints and conclusions of others.

Due to the limited time available for conducting interviews and field trips, the majority of the information was gathered in the Edmonton area.

Reliance has generally been placed on the results of testing of materials by others, as no testing facilities were available to the writers.

(d) Subjects not covered in Report

Through observation, reading and discussion the writers have become aware of the many individual subjects which could be included under the principal heading of Roofing. Only a few of these are discussed in this report. Subjects which have not been dealt with, other than a possible mention, include:

Cold process roofing
Liquid applied roofing
Rolled roofing
Smooth surfaced roofing
Shingle roofing
Coal tar pitch and pitch products
Composition and properties of asphalts
Permeability ratings of materials
Wind uplift
Cold applied liquid adhesives
Mechanical fasteners
Caulkings and mastics
Cutbacks
Emulsions

Should the readers wish to examine these subjects, they are referred to the list of references accompanying this report.

II GENERAL

(a) Understanding Basic Principles

Building designers should be familiar with the physical laws concerning air, moisture and heat, if they are to approach building design responsibly. There must be a basic understanding of how air, moisture and heat affect a building and its components. With specific reference to roofing it is quite evident by examining a number of roofing failures that the designers of the built-up roofs which failed did not understand the principles of physics involved; at times it appeared that the designers were attempting to defy the laws of nature. Quoting (abridged) from N.R.C. Technical Paper #191, "Roofing - Past and Present" by M. C. Baker, "......early and serious malfunctions and deterioration of some of our buildings indicates a lack of appreciation of many factors which involve the unchanging laws of physics and chemistry, and their effects on some of our complex assemblies of building materials. Vapour pressure, moisture migration, air and heat flow, light and sound transmission, volumetric change and electrolytic action are not mysterious phenomena of interest only to engineers and scientists, but are some of the mechanisms that daily affect the combination of materials that go to make up our modern buildings. Architects (and engineers) must reassert themselves as technical leaders, and to do this they must know more about nature's laws with which they can generally cope, but which they cannot change and are ill-advised to flout."

There are several excellent papers published by the Division of Building Research, National Research Council, dealing with roofing and built-up roof performance and these are recommended for study by all professional people engaged in designing buildings (Ref #1 - 24 , 38, 47, 56, 67, 68, 69, 70, 73, 74). Terms such as Relative Humidity, water vapour, condensation, permeability, vapour pressure and partial pressure, to mention only a few, should be familiar to the designer. In this way, the designer will at least recognize a situation as being problematic. Once the problem is recognized as existing the assistance of those people in whose field the problem lies can be sought out.

(b) Comparison of Old and New Roof Systems

A building can be most briefly described as a protection from some aspects of the natural environment. The space enclosed by the walls houses an artificially produced and controlled climate, and the roof being the uppermost part of the enclosure, protects the whole from the sun and the rain.

Years ago, a roofer installed only the multi-layered felt and pitch membrane and the flashings. Today the roofer has become responsible for not only the membrane, but also the vapour barrier and the insulation.

Today's built-up roofs differ from those of twenty years ago in two main ways. Generally speaking, the roof of today is flat, and the asphalt and felt membrane is applied directly to the insulation. In all probability this change was dictated by changing aesthetic and economic considerations. Unfortunately, the change has violated two important principles of sound construction; a built-up roof should shed water, not hold it, and an insulation should be free to breathe to the air mass which is at the lowest vapour pressure (cold side).

Old buildings were most often constructed either with integral sloped roof structures, or flat roof structures supporting falsework to produce a sloping roof. Most of the older buildings had no insulation in either the walls or the roof structure. When insulation was installed, it was generally located just above the ceiling, in the same manner as it is installed in most houses today. The roof was designed to shed the water, and the insulation was on the cold side of the structure.

Shingled or tiled roofs cause very little trouble and seldom leak in spite of the many openings through them. (Ref # 1 - 67). To prevent the leakage of a flat roof, a continuous membrane must be provided, in which there are no holes (except drains) through which water can move. Today's roofs require a far greater appreciation of the physical interaction of materials than did the old style roofs. Workmanship is of major importance today, however, the best of workmanship will not produce a leak-proof roof, if either the roof or the roofing design is faulty.

It is realized there are many problems which engineers and architects must solve in order to provide a series of sloping surfaces on the roof. A little thought and ingenuity will surely produce satisfactory answers. Structural framing systems must be considered individually and an answer found for each system. Many ideas come to mind, however, it is not within the scope of this study to determine what these answers might be. There will undoubtedly be a slight increase in the cost of structural framing, resulting from sloping the roof surface, but this cost by rough calculation will be generally only a small percentage of the roof cost, and an almost insignificant percentage of the overall building cost.

Todays buildings differ from those of twenty years ago, principally as a result of the desires and the demands of the occupants and owners for very sophisticated interior climate control. The pressurization of building interiors to eliminate draughts and the very significant increase in humidification have led not only to an increased number of problems with building walls and windows, but with roofs as well. For far too many years, while the interior climates were being changed the basic approach to building design was not changed. It is just within recent years that designers have started to "wake up" and recognize the true causes of the poor performance of many buildings.

(c) Factors Contributing to Roofing Failures

In order to appreciate the following pages of this report more fully, let us look at the factors contributing to roofing failure, and the mechanics of roofing failure.

Events which lead to failure can be thought of basically as controllable and uncontrollable. (Ref #9). Controllable factors include those things dependent on the human element, such as design, construction, quality of materials, workmanship, roof top traffic, maintenance, building humidity, etc. The uncontrollable factor is the weather. The quality of the roof, then, is largely dependent on the human element, which is generally difficult to control, and the weather. The roofing contractor is seldom able to coordinate his operations with the whims of nature. To quote from University of Minnesota Bulletin #34, "Principles Affecting Insulated Built-up Roofs" by C. E. Lund and R. M. Granum. "One of the greatest problems a roofing contractor must experience is the demand for immediate installation of the roof, regardless of the weather or the condition of the roofdeck."

The primary reasons for roofing failures are:

1. Faulty workmanship
2. Faulty design of built-up roof and flashings
3. Faulty design of supporting structure
4. Faulty materials
5. Mechanical damage

The above are general classifications. Some details of these classifications are:

1. Overheating of asphalts.
2. Application of too little asphalt.
3. Application of roofing during poor weather, or on a rough, wet or frosted deck, or deck of insufficiently cured concrete.
4. Improper storage of materials.
5. Felts of completed membrane left exposed to the elements.
6. Insulation improperly placed or poorly anchored.
7. Insufficient gravel bedded in pour coat.
8. Differential movement of the components of the roof system, structural deck, insulation, felts, flashings and asphalt.
9. Lack of proper control joints in the roofing.
10. Improperly placed control joints.
11. Insufficient insulation.
12. Lack of slopes to drain.
13. Non-sloped flashings.
14. Lack of control joints in the structure.

15. Lack of exfiltration stops in wall cavities and control joints.
16. Omission of, or poorly installed vapour barrier.
17. Delamination of factory-made multilayer insulation.
18. Excessive moisture content in insulation.
19. Over or under saturation of felts with asphalt.
20. Poor dimensional tolerance of insulations.
21. Asphalt not "blown" properly to specified softening point.
22. Gravel coated with dust or dirt.
23. Improper protection of portions of roofing already installed, in areas where construction is still in progress.
24. Puncturing of membrane resulting from physical use of roof area.

One or any combined number of the factors just listed will probably result in the development of one or more of the following mechanisms contributing to failure of the roofing system:

1. Splitting of the membrane.
2. Buckling of the membrane.
3. Bubbling or blistering of the membrane.
4. Chemical and physical degradation of the asphalt.
5. Wetting of the insulation resulting from either 1, 2, 3 or 4 above.
6. Wetting of the insulation resulting from flashing leaks at parapets, control joints and other roof projections.
7. Wetting of the membrane resulting from migration of moist air through the structural deck.
8. Wetting of the insulation resulting from migration of moist air through wall cavities, thence laterally into the roofing "sandwich".
9. Wetting of the insulation resulting from migration of moisture from green concrete.
10. Wetting of insulation resulting from moisture entrapped in the deck or insulation or insulation joints during construction of the built-up roof.
11. Super wetting of either the top or bottom surface of the insulation resulting from migration of most of the normal moisture content of the material to either the top or bottom surface of the insulation.
12. Accumulation of moisture in the bottom roofing felt through the same process as described in 11 above.
13. Wetting of insulation resulting from punctures due to use (foot traffic, falling object, etc.).
14. Wetting of insulation resulting from loss of asphalt in or between felts.

After reading the foregoing lists, it is not difficult to see why carelessness in design and workmanship generally results in costly failures.

Explanations of the mechanics of failure can be found in the reference literature. The explanation of items #7 and 8 above, however, are not too commonly encountered.

Water vapour can enter the roof insulation by direct diffusion through the roof deck, and by diffusion into the building walls. The diffusion through the roof deck and thence into the roofing system is generally overcome by the installation of a vapour barrier directly over the deck. Diffusion into the walls is most often overcome by using either a plastic film or paint film on the inside face of the wall. Very often, probably most often, this interior vapour barrier terminates just above ceiling level, in the case of the ceiling being suspended. It is essential that plaster and paint or other vapour barrier be carried above the ceiling level to the underside of the floor above. Suspended ceilings will not prevent water vapour from entering the exposed wall above the ceiling and travelling up to roof level through the blockwork, or through the cavity between block and veneer.

(d) Effects of Heat and Moisture

The effects on a roof system of heat, solar radiation, water and water vapour must always be kept in mind. Differential movements of building and roofing components have serious effects on the water tightness of the roof membrane. Solar radiation besides causing physical and chemical degradation of roofing asphalt, causes high linear expansion of the membrane. Water ponded on roof membranes has very serious effects on the membranes during fall, winter and spring, when freeze-thaw cycles are frequent. Water vapour diffusing into insulation and felts will lead to loss of efficiency of the insulation, and ultimately to complete failure of the membrane. Figure #1 shows the coefficients of thermal expansion of various building materials, and is worthy of study. Figure #10 shows the change in unit linear expansion of asphaltic roofing membranes in different temperature ranges.

Thermal movements of major degree result from solar heating and nightime cooling. Roof membranes placed over insulation may attain temperatures 100°F. above air temperature due to solar heating and may attain temperatures of 15°F. less than air temperature due to radiative cooling. Roof membranes over insulation on a hot sunny day, might easily reach temperatures exceeding 200°F. (black surface). A gravel surfacing most probably will result in a drop of about 20°F. in membrane temperature, however, the membrane temperature may well still be 100°F. above air temperature. Snow cover tends to stabilize the temperature of a roof membrane, so that there is little difference between outside

FIGURE I

PROPERTIES OF CONSTRUCTION MATERIALS

MATERIAL	Coef.of Exp. In./In./°F. x 10 - 6	Tot. Exp. 100' & 100° Inches	Percent Deformation Over 100°F.	Tensile Rupture Stain Inches/100'	Relative Rupture Load
Aluminum	13	1.54	0.13	4.7	
Asbestos-Cement	5	0.60	0.05		
Brick (hard)	3.1	0.37	0.03	0.2	
Bronze	10.1	1.21	0.10		
Clay Tile	3.3	0.40	0.03		
Concrete (normal)	6.5	0.78	0.07	0.1	
Copper	9.8	1.18	0.10	3.5	
Glass	4.7	0.56	0.05		
Granite	4	0.48	0.04		
Lead	16	1.92	0.16		
Limestone	3.8	0.46	0.04	0.07	
Marble	5.6	0.67	0.06	0.07	
Plaster (sand)	9.2	1.10	0.09		
Steel (carbon)	6.7	0.80	0.07	1.5	
Asphalt-Organic) MD	11) (a)	1.2) (b)	0.10) (c)	12) (d)	4.0 P
Membrane) CD	21)	2.5)	0.20)	14)	2.5 P
Asphalt-Glass) MD	18)	2.2)	0.18)	13)	1.5 P
Membrane) CD	26)	3.1)	0.26)	13)	1.0 P
Wood (along grain)	2.5				
Wood (across grain)	25				
Plywood	3.6				
Foam Glass	4.6				
Polystyrene	40				
Polyurethane	35				

(a) See detailed table (Fig. #9)

(b)(c) In temperature range - 30°F. to + 70°F.

(d) Membrane (average) breaking strain @ -30° = 1%
Membrane (average) breaking strain @ +70° - 1.5% to 2.0%

air temperature and membrane temperature, whether it be day or night, or the weather sunny, cloudy or windy (Reference #7).

Asphalt exposed to high temperatures and sunlight deteriorates through photo-oxidation, and in addition to cracking due to increased brittleness, is gradually dissolved by precipitation. The asphalt is the actual water resistant material in the built-up roof and its gradual deterioration through either chemical or physical processes will eventually lead to failure of the membrane.

The presence of moisture in a built-up roof system is probably most often associated with its effect on the insulation. Besides affecting the insulation, moisture has a serious effect on the roof membrane. Any moisture trapped within the roof membrane, either as free water between the plies of felt, or as water absorbed into the fibres of the felt, will evaporate and form vapour. This change of state from liquid to vapour creates a pressure sufficiently large to lift the membrane and produce large blisters. The formation of a blister, or "pillow", will not generally result in an immediate leak in the membrane; it is the continued stretching and relaxing cycle, from day to night, that eventually causes the felts to fail. Failure of the membrane in the blister area may be hastened by the loss of bitumen from the sloping "sides" of a high blister.

The quantities of moisture required to produce blistering are very small. Water will expand to form approximately 1600 times its volume of water vapour, at normal temperature and pressure, thus one cubic inch of water will expand to nearly one cubic foot of water vapour. This volume is not reduced appreciably by an increase in pressure of 10 pounds per square foot. A pressure of 10 pounds per square foot (the probably maximum weight of roofing and gravel) is sufficient to lift a membrane from its substrate, or separate roofing plies from each other.

The effects of heat and moisture must be considered most carefully in the design of roofing systems.

(e) Limitations, the Human Element and Bias

Concrete is not to be disregarded as a satisfactory building material simply because it cracks upon curing, and neither is timber to be disregarded as a satisfactory building material simply because it rots upon continued exposure to dampness. Rather, both of these materials are highly acceptable in construction if their use is designed to take into account the limitations of each. The cracking of concrete is controlled through properly designed control joints and reinforcing steel, and through proper mixing, placing and curing procedures. The rotting of wood is controlled by proper protection from moisture, or by proper continued immersion in water.

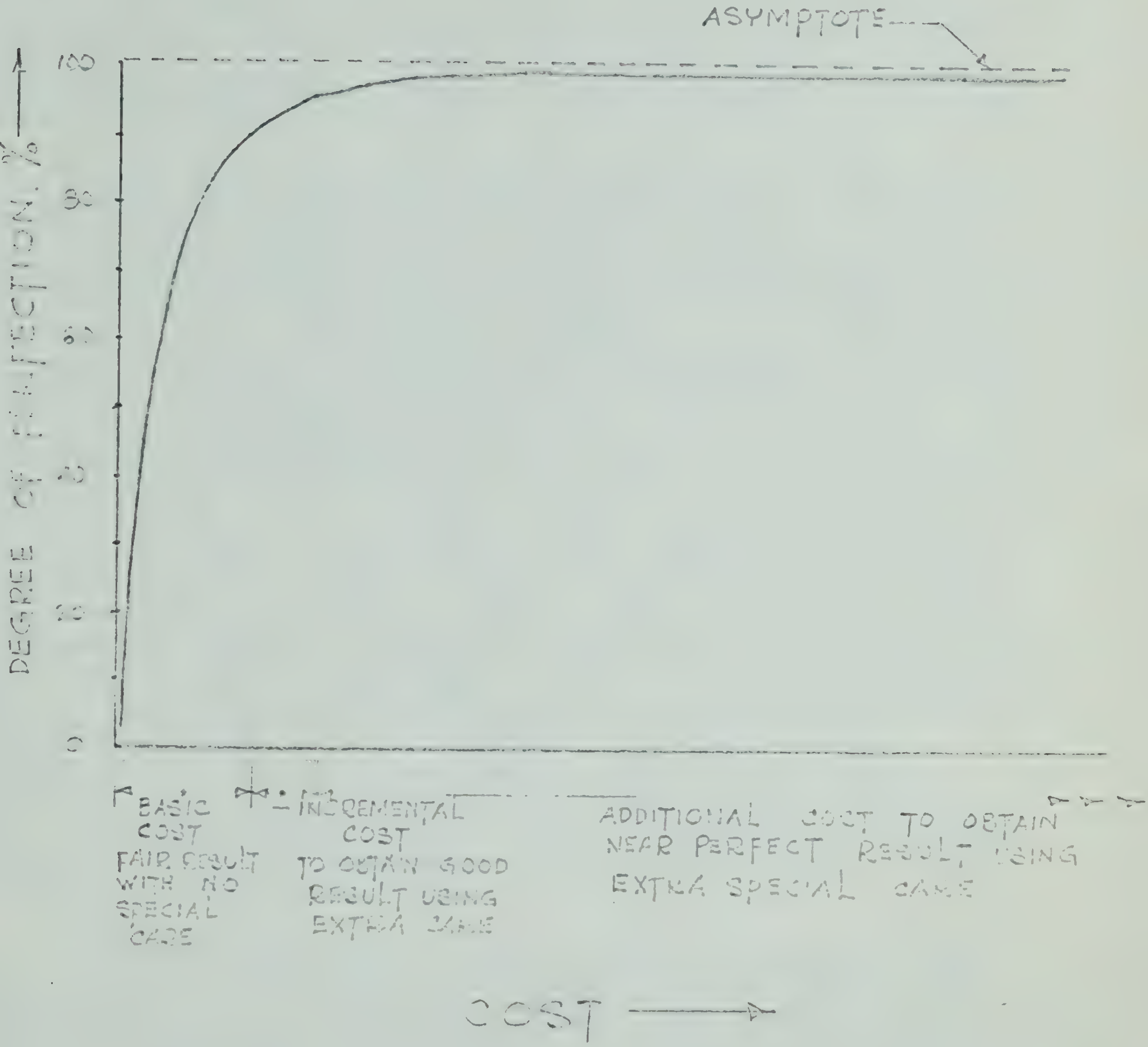
Limitations recognized during design may not always be appreciated during construction. A good design can fail due to poor workmanship or use of poor or unsuitable materials. On the other hand, many poor designs have no doubt been made to work by an experienced and conscientious roofer, at his own expense, simply because he has not wished to become involved in a failure of his construction. Limitations must be recognized and should not be so narrow that they render the practical field application of the products "critical". Limitations established in the laboratory and under carefully controlled field tests, should be examined carefully and then tempered prior to their being used as a guide to actual on-the-job conditions. A roof insulation cannot be condemned simply because it rots when exposed to moisture. The fundamental concept in the use of insulation is that it must be kept dry. All insulations do not rot when they become and remain wet for a length of time, however, all insulations lose most of their insulating value if their moisture content becomes unduly high. The prime requirement, then, in order that a roof insulation insulate, is that it be kept dry and at a low moisture content.

Now, in order that moisture not get into the insulation, the construction which protects the insulation must be moisture proof. This means that the primary membrane over, the vapour barrier membrane under, and the flashings around the insulation must hold moisture away from the insulation. Since the structure, the insulation and the roof membrane all change dimension with change in temperature and moisture content, the detailing of the roof must be such that the expansive-contractive properties of the materials making up the roof system are properly allowed for. A large area of built-up roofing acts similarly to a large area of concrete slab on grade. If sufficient control joints are not introduced into the construction, the large area may become overstressed, with the stresses being relieved through cracking. Once the roof membrane has cracked the prime function of the roof membrane has been lost.

There must be allowances made in the design for the human element; some imperfect workmanship must be tolerated. It is naive to think that, under the present system of competitive bidding, the low tenderer could allow for perfection (Figure #2).

There has been noted a great deal of prejudice on the part of designers, manufacturers and contractors, with respect to design, construction techniques and materials used in the construction of built-up roofs. The profit motive seems ever present and understandably, designers, manufacturers and contractors who have had unfortunate experiences with certain types of roofing construction, are hesitant about repeating these experiences. A designer may not be particularly interested in why a particular type of roofing or a particular type of roof insulation has given trouble on one of his projects; he is much inclined to wait until someone else, at their expense, proves to his satisfaction that the troubles to be expected using these materials are

FIGURE 2



Assumed Relationship of

Cost of Roof Construction Versus

Degree of Perfection as Produced through

Design, Materials and Workmanship

minimal. Unfortunately, it is suspected that the prejudice does not all stem from experience, but that a large portion stems from hearsay-- "many people are inclined to believe what they want to believe". In actual fact, many reports of failures heard of and subsequently investigated by the writers were found to be out of proportion to fact, and substantially biased.

People have personal preferences; these usually stem from past satisfaction derived from the use of a particular product or system of design. It seems obvious that human nature must enter very largely into roofing design, and that this factor should not be overlooked. To quote again from N.R.C. Technical Paper #191 "Roofing - Past & Present", by M. C. Baker. "There is a tendency to think of any particular material or system as being good or bad, depending on the architect's experience with its performance on an actual building. This approach assumes that durability is a fundamental property of the material or system. Nothing could be further from the truth. The performance of a material or system depends on the environment to which it is exposed and the degrading effect of service. A proper understanding of building science helps one to recognize the pertinent factors affecting the performance. It is then possible to analyze designs systematically as to the probable performance, and choose materials or systems to satisfy the varied requirements". Almost too frequently, when a failure of a roof involving a particular product was brought to the attention of the manufacturer of that product, the manufacturer could not agree that it was the fault of his product -- "it was improper application or design or handling, etc.". There were many projects cited with the comment, "We've had no trouble at all with these and they all employed our product". It seems, however, that the owner of a building with a leaking roof is not interested in the other thousand that don't leak -- he is conscious only that <u>his</u> roof leaks.

Almost without exception, roofers questioned about glass felt stated they did not like to use this material. The reasons given for this dislike were not reasons such as "hard to work with" or "won't stand jobsite handling", but were reasons of personal experience with failures of glass felt roof membranes. The roofers, understandably, do not want to be involved with roofing failures and the attending costs of repair.

Generally speaking, it seems that building sub-trades feel they are not obligated to determine the reasons for failure of their work, as long as the work was executed as specified. Why should they be obligated? The determination of reasons for failure can be very time-consuming and expensive. If a particular material is associated with failures of systems utilizing the material, and the tradesman has a choice of materials, the tradesman will not choose to work with this material associated with failures. Unfortunately, the reasons for the failure of the material may have little, if anything, to do with the material itself. The tradesman's attitude seems to be "when someone

solves the problem and proves to me it is solved, I will then use the material in question".

An attitude seems to exist within the Department, at present, in which any roofing failure involving "Stramit" or any failure involving glass felts automatically becomes the fault of either the Stramit or the glass felts. The same situation seems to exist regarding "Roofmate" and "Zonolite insulating concrete". It appears that "once bitten, twice shy", is the attitude adopted by designers, owners and contractors. Little time appears to have been in the past spent by any but the manufacturer of the material criticized and the Provincial and Federal Government Research Councils, in an attempt to determine the true causes of failure. Today, the Alberta Roofing Contractors Association through regular meetings of their Technical Committee, are working toward the solutions of the many problems arising in the roofing industry and this organization is to be commended for its efforts.

III BUILT-UP ROOFING MATERIALS

A built-up roof, as most widely defined, consists of a membrane of roofing felt and asphalt. (Coal tar pitch is little used today, so will not be discussed). The vapour barrier and insulation have not, in the past, been considered a part of the built-up roof, however, as previously noted in the Introduction, a built-up roof will be considered in this report as including a vapour barrier and insulation. (Ref. 1 - 24).

Asphalt is a material that behaves as a viscous fluid at some temperatures and as an elastic solid at lower temperatures. It is referred to as a visco-elastic material.

Roofing asphalts are classified as Type I, Type II and Type III. The classification is based on the softening point (S.P.) of the asphalt. The softening points of the three types of asphalts noted are Type I - 145°F., Type II - 170°F. and Type III - 200°F., as determined by the standard ring and ball test procedure. The requirements for asphalts to be used in the construction of built-up roof coverings are contained in C.S.A. Standard A 123.7. Crude asphalt is "air blown" at around 500°F. and the degree of oxidation that takes place during this operation primarily determines the softening point of the material.

In order for an asphalt to function as a roofing material, it must be adhesive and cohesive. It must not harden excessively through oxidation and should resist excessive softening at high temperatures. Different types of asphalts used together must be compatible. (Coal tar pitch and asphalt are not generally compatible, and the combining of a material containing pitch with a material containing asphalt should be avoided). The asphalt used on a roof is the only material on the roof which will render the construction watertight. The felts and the gravel are employed to maintain the asphalt.

The primary function of a roofing felt is to reinforce and stabilize the roofing asphalt.

Two basic types of felts are manufactured, these being organic and inorganic. Organic felts are manufactured from wood fiber, cotton and jute fabrics. Organic felt is most commonly referred to as rag felt, although today there is very little cotton fabric used in its manufacture. Rag felt is made primarily from wood fiber. Inorganic felts are of two main types, these being asbestos and glass. There seems to be very little asbestos felt used in Alberta -- the major inorganic felt is a glass fiber product.

Roofing felts are produced in rolls most generally 36 inches wide, and containing 432 square feet of material (sufficient for one

square of 4 ply membrane). The glass or paper fabric is saturated with a low S.P. (about 110°F.) asphalt. Glass felts, and the heavier felts (base sheets) are generally coated with a higher S.P. (about 170°F.) asphalt, to prevent sticking of the rolled material. Some manufacturers coat one surface with a fine mineral grit to prevent sticking in the roll.

Roofing felts, besides being used for the roof membrane, are used to produce vapour barriers. A vapour barrier is generally a light roof membrane applied directly to the structural deck. There are, however, other types of vapour barriers, applied at locations other than that just noted.

Roof insulations are used to prevent the flow of heat through roofs. Heat flows both ways through roofs and this heat flow is undesirable.

Insulations used on roofs are composed of organic or inorganic materials of either a fibrous, cellular, granular or foamed nature. They are available in preformed units, generally of a variety of thicknesses, sizes and densities. Roofing insulations are generally of the "rigid board" style, however, there are some which are poured in place, much like a concrete topping. In Alberta, the most commonly used rigid insulations are made of wood fiber, grain straw, polystyrene foam, glass fibre and obsidian. Others available are made from compressed granular cork, foamed glass, beaded glass and foamed polyurethane. Poured-in-place insulation in Alberta is most often manufactured from expanded mica (Vermiculite), although an expanded volcanic glass aggregate (Pearlite) is also available.

Of all the materials used in the construction of a built-up roof, the insulation seems to be the most controversial. The physical properties of roof insulations vary widely, and there is considerable difference in performance of the different insulating materials under a variety of conditions.

The primary function of a roof flashing is to protect certain parts of the roof membrane from the elements.

Flashings are most generally manufactured from galvanized iron, copper, aluminum and lead. Some flashings used are simply a heavy metal foil paper or a heavy mineral surfaced asphalt felt. Stainless steel is sometimes used for flashings in corrosive atmospheres.

The fundamental reason for the use of mineral aggregate in the construction of a built-up roof is the protection of the roofing asphalt.

Not all built-up roofs are designed to be covered with mineral aggregates, however, those that are are covered with clean and sound

natural gravel, slag or mineral chips. These materials are usually well graded to a maximum size of 5/8 inch. Pre-manufactured items, such as rolled selvage edge roofing and asphalt shingles have a very fine mineral chip factory imbedded in the surface coating of asphalt.

IV DISCUSSIONS AND RECOMMENDATIONS REGARDING MATERIALS

(a) Asphalt

Most of the roofing asphalt used in Alberta is manufactured from oil produced in the Lloydminster, the Pembina and the Southern Alberta areas. Local roofing contractors purchase roofing asphalt both in 100# solid cartons and as bulk fluid. The major producers are Imperial Oil Company and Husky Oil Company. One of the major distributors in the Edmonton area is Building Products Limited.

Since the asphalt is the sole material in a built-up asphalt, felt and gravel roof that can render the roof waterproof, it should be considered as the most important of the materials used in roofing. It was found by the writers, however, that less was known about asphalt by those people specifying its use, than was known about any other of the roofing materials.

A number of the people interviewed were asked by the writers, "Why is Type I asphalt so widely specified in Alberta, for flat or near-flat roof construction?". Strangely, no one could come up with a definite answer. Very probably, the change to the low softening point asphalt came about at the time the flat roof was popularized, approximately twenty years ago. Prior to 1950, high softening point asphalts were most generally used. The sloping roofs required an asphalt that resisted sagging in hot weather. High softening point asphalts are less susceptible to sagging. The major disadvantage of a higher softening point asphalt is its tendency toward becoming excessively brittle in cold weather. Having been oxidized to a relatively high degree during manufacture, the Type II and Type III asphalts have been somewhat "pre-weathered". In effect, they have a "head start" on deterioration. The oxidative process continues during the service life of the asphalt product as a result of atmospheric exposure. It is interesting to note that sloping roofs (as low as 1" per foot) exposed to the same elemental conditions as flat roofs, are invariably specified as requiring Type II or Type III asphalt.

Although no definite conclusions have as yet been drawn by researchers regarding the effects of weathering on the increase in hardness of asphalts (Ref. #3), the writers found that a number of roofing contractors have been going back to the use of Type II asphalt on flat roofs, mainly because through practical experience they find that it gives better service. There appears to be presently too much emphasis placed on the argument that Type I asphalt is "self healing". It may be "self-healing" on dead level surfaces, but under sloped flashings and on blisters or buckles, there appears to be a pronounced acceleration in flow down the slope when the membrane is at high temperatures.

There is some disagreement amongst researchers, and also amongst roofing contractors, regarding the use of greater thicknesses of asphalt in the construction of a built-up roof. Older specifications required well over 200 lbs. of asphalt per square, whereas today, most specifications call for a total of 135 lbs. to 160 lbs. per square. It has been argued that the greater the thickness of asphalt, the greater is the tendency toward cracking of the asphalt (Ref. #18). The argument has not as yet been resolved, and is not likely to be, it would appear, for some time. The most popular opinion of the people interviewed, and of authors of articles on roofing, is that lack of sufficient asphalt and overheating of asphalt contribute greatly to poor performance of built-up roofs.

By referring to Fig. #7, it can be seen that the cost of adding 90 pounds of asphalt and 100 pounds of gravel to the quantities of materials presently specified per square is about $4.50 per square, or 4½¢ per sq. ft. Is it really economical to "save" this amount of money?

Temperatures to which asphalt is heated during manufacture and

Page 19, third paragraph: The third and fourth sentences should read:

Below 350° F there is a lack of workability and adhesion. Above 450° F. the asphalt loses volatile oils __________ .

the roofing operation.

During field inspections, the writers found few asphalt kettles with accurate thermometers. Generally the temperature was determined by "observation". Very hot asphalt is much easier to mop, and goes a lot further. The use of overly hot asphalt, then, results in reduced labour, reduced quantities applied, and a "pre-weathered" material being applied. It is doubtful if the generally specified 20 lbs. per square of asphalt between plies can be applied using Type I asphalt at temperatures much over 400°F.

Cold process roofing asphalts have not been discussed in this report. It appears that Alberta roofers are not inclined to use this type of material to any great extent. One product, however, called "Alumanation" is presently being used by the D.P.W. maintenance section. Reports of the performance of this material have so far been favourable.

A roll of rag felt weighs about 60 pounds. When this roll is first placed on the asphalt mopped over the insulation, its weight squeezes out a considerable amount of hot asphalt from the interface between the felt and the insulation. The hotter the asphalt, the more is squeezed out. As the felt roll is run out on the roof, it becomes progressively lighter in weight and the wave of asphalt which can usually be seen running ahead of the roll becomes smaller (Photos #28 & 29). The thickness of asphalt which remains between the felts and the insulation at the "finish" end of the rolling operation is generally greater than that which remains at the "start" end of the rolling operation. It

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Temperatures to which asphalt is heated during manufacture and in preparation for application are critical. The maximum temperature has been quoted by some manufacturers as 500°F., however, 450°F. is considered by researchers as being the top limit. Below 350°F. the asphalt loses volatile oils and other fractions and becomes thinned to a degree which precludes application of the required quantities during the roofing operation.

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require the material to be perfectly dry, in order that it bond properly to the asphalt. In theory this sounds reasonable. Dry aggregate, however, may be dusty or covered with foreign material which will reduce its bonding quality. If the spreading operation is run with the wind, any dust in the mineral aggregate will be blown ahead of the spreading, forming a thin bond-breaking skin on the hot asphalt. This will not happen if damp aggregate is used. The experience of local roofing firms seems to indicate that as good or better a bond of aggregate to asphalt is achieved by using slightly damp aggregate.

The most commonly used roof surfacing aggregate in Alberta is natural gravel. This material is reasonably light in colour, non-translucent and adequately reflective. It is generally hard enough to resist abrasion and frost action, and is not brittle. It is important that roofing gravel be properly graded, to aid in complete roof surface coverage. "Mineral Aggregate Roof Surfacing" by D.C. Tibbets and M. C. Baker (Ref. #1 - 65) is an excellent paper dealing with roofing protection, and should be studied by building designers and specification writers.

Most specifications (in Alberta) call for the maximum size of aggregate to be 5/8". The writers were not able to determine for what reasons this maximum could not be increased to 3/4" or possibly 1".

(c) Felts

Invariably, when the writers discussed felts with contractors and manufacturers, the discussion time was spent mainly on comparing glass felts with rag felts. The following were the most common comments regarding rag felts:

1. Roll weight is often not constant.
2. Some rolls will not roll straight.
3. Some materials are not flexible enough - too brittle in cold weather.
4. Felt hardness not always constant - this causes crooked rolling.
5. Felts by some manufacturers unevenly impregnated - some spots quite dry.
6. Absorb high percentage of moisture when wetted, and expand considerably.
7. Cutoffs difficult to make because felts tend to crack when cold.

8. Generally, rag felts are easier to lay than glass felts, and cause fewer callbacks for roofing repairs.

The most common comments about glass felts were:

1. Generally felt by roofers that glass felts split too easily and often in winter.

2. Felts don't fishmouth when layed, but they wrinkle - edges lay flat and don't curl.

3. In warm weather, workers cannot walk on glass felts for some time after laying - boots and equipment stick to the felts and pull out pieces. The felts wrinkle up if walked on.

4. Insulation must be taped if glass felts are used, to prevent loss of bitumen through the felt and into joints in the insulation.

5. If edges of felts are left exposed to weather, asphalt bleeds out, but no damage is done, since the felts do not "wick" water.

Of all the contractors interviewed, only one stated that, if he had a choice, his choice would not necessarily be rag felt. All others stated they would not use glass felts, based on their past experience with the material. The writers attempted in earnest to determine the reasons for this apparent general dislike of glass felts, and to determine whether or not it was the felts themselves or specific misapplication of the felts, or a combination of factors which caused the troubles with glass felt membranes.

Glass roofing felts are manufactured in Alberta by Fiberglas of Canada Ltd. and Peace River Glass Ltd. Peace River Glass (P.R.G.) is very active in promoting the use of glass fabric roofing felts, whereas Fiberglas of Canada concentrates more on promoting their lines of insulation. Each company uses an entirely different process for manufacturing the glass fibers and the fiber mats produced by each company are quite different. The saturation of the mats with asphalt to produce the felts is done by Building Products Ltd., or by other saturators.

After early 1966, P.R.G. discontinued the sale of the standard 8# felt. Their specification for roofing felt was then changed to 13# material. As of June 1967, P.R.G. discontinued the sale of 13# felt and now they make available a 15# felt only. A 15# felt (often referred to as a #15 felt) weighs fifteen pounds per hundred square feet or "square". Up until early 1966, P.R.G. specified felt saturation with Type III asphalt; however, Type II is now specified. Saturation with a Type I asphalt was considered, but the manufacturers concluded that it

was more advantageous to sacrifice some of the better cold weather properties of Type I than introduce hot weather sticking and bleeding by going to Type I.

Fiberglas of Canada produces a 13# felt in addition to their standard 8# felt. The 13# felt was introduced about 1964. Both of these felts are saturated with Type II asphalt.

Some of the more well-known Alberta distributors of rag felts are Building Products Ltd., Canadian Gypsum Co., Domtar, Canadian Johns-Mannville, I.K.O. Roofing Products and Mac Asphalt. It was found that several "brands" of felt were actually manufactured by one company. Johns-Mannville felts, for example are manufactured for J-M by Building Products Ltd.

Several roofing contractors complained that one Alberta manufacturer had very poor quality control. Felts were either over saturated or under saturated, and were not at all uniform in properties. An undersaturated felt, or "dry" felt, when incorporated into a built-up roof, is an invitation to trouble.

Rag felts are saturated with a very low S.P. asphalt (110° to 120°). Rag base-sheets (minimum weight 35 lbs.) are further glaze-coated with Type III asphalt.

Asbestos fiber roofing felt is distributed in Alberta by Canadian Johns-Mannville. This type of inorganic felt is used primarily for smooth surfaced roofs (no mineral aggregate cover). The smooth surface roof does not appear, however, to be too widely used in Alberta, compared with the mineral aggregate surfaced roof.

Rag felts are susceptible to considerable volumetric change upon increase of moisture content. Studies indicate that the expansion can be as high as 0.2% to 0.4% in the machine direction, and 1.1% to

<u>Page 23, seventh paragraph:</u> In line four, change 80% to 50%.

of a saturated felt, the shrinkage of the felt can exceed the original expansion. It can readily be understood why rag felts should not be allowed to become wet during storage, or during installation, or during service, for this and many other reasons.

Rolls of felt should be stored on end, away from moist surfaces. If rolls are stored horizontally, or if the ends of the rolls get wet (Photo #1), these will be most difficult to lay properly. Fishmouthing, wrinkling and curling of the felts will result when improperly stored material is layed (Photos #24, 25, 26, 35).

In order to achieve a more positive bonding action, many rag felts are perforated. These perforations are only 1/32 inch in diameter and are located about ½ inch on center each way. The writers

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Rag felts are susceptible to considerable volumetric change upon increase of moisture content. Studies indicate that the expansion can be as high as 0.2% to 0.4% in the machine direction, and 1.1% to 1.5% in the cross direction (Ref. #18). Up to 80% water, by weight, can be absorbed by an asphalt saturated rag felt. Upon the drying out of a saturated felt, the shrinkage of the felt can exceed the original expansion. It can readily be understood why rag felts should not be allowed to become wet during storage, or during installation, or during service, for this and many other reasons.

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In order to achieve a more positive bonding action, many rag felts are perforated. These perforations are only 1/32 inch in diameter and are located about ½ inch on center each way. The writers

did not note any literature outlining tests conducted or studies made regarding the relative merits of using perforated felts in a built-up membrane. Perforated rag felts seemed to be quite popular amongst roofers.

A roof membrane is most commonly specified as consisting of 4 plies of felt, all plies being layed simultaneously in the same direction (Fig. #3). This method of laying is probably the most convenient for the roofers, even though it does not appear to be one which makes sufficient allowance for faulty workmanship. In the opinion of the writers, a superior method of laying the felts is "two on two". This method produces effectively, a double two-ply membrane (Figure #4). In laying a membrane following this procedure, both two-ply applications must be done the same day. Instead of laying the two, two-ply sections in the same direction, they can be layed perpendicular to each other. Because of the different properties of felts in the machine direction and in the cross direction (Fig. #9), it is probable that a membrane of uniform properties in each direction might be obtained by laying half the felts perpendicular to the other half. This has been done by roofers on occasion, although the procedure can complicate the roofing operation considerably. The possible advantages of the perpendicular two-on-two system have not been investigated. The writers did not note any reference to the half-each-way system in the literature studied.

The major complaint regarding glass felt membranes is that they split. The splits have been found to be nearly always parallel to the length of the felt. Particular advantage might be gained by using the two-on-two perpendicular system with glass felts. Glass felt membranes, however, are generally composed of one less ply than are rag felt membranes. The reason for this reduced number of plies is not too clear, although it would appear to be related to both manufacturers' test data, performance data and competitive pricing. A one-on-two system of laying felts is not recommended, since the effectiveness of the one-ply component is doubtful.

All the failures of glass felt membranes investigated by the writers appear to involve 8# felts. No specific instance of the failure of a membrane which utilized 13# or 15# glass felts has been brought to the writers' attention. It may well be that, in changing to the heavier felts, the manufacturers suspect the light 8# felt could be a primary reason for the splitting of glass felt membranes. This suspicion, however, is just supposition on the part of the writers.

Researchers and roofers are in agreement that all the plies making up a membrane must be firmly bonded together with a continuous coverage of asphalt (in the case of asphalt being used). There is agreement that the felts should be protected from the weather by immediate covering with asphalt and gravel upon completion of laying, however, many instances were noted by the writers where this procedure was not

carried out. Specifications generally call for the felts to be "broomed down" to effect proper adhesion of the plies. Brooming down of glass felts on a hot day does not appear practical. Brooming down of rag felts, in the many roofing operations witnessed, was not in any instance observed being carried out.

The writers questioned researchers and roofing felt manufacturers regarding possible merits of a combined glass felt-rag felt membrane. Few opinions were ventured. A look at the possibilities of a combined glass felt and rag felt membrane might well be worth-while.

One roofing system known to the writers employs the parallel fiber type of glass fabric. This material contains 20 fibers per inch each way, weighs approximately 1.8 oz. per sq. yd., and has a breaking strength of roughly 100 pounds per inch at a strain of 3%. Below this strain, it is said to have almost full elastic recovery. There would appear to be merit in using this material in a built-up roof. Further investigation is recommended.

(d) Insulation

Of all the components of a built-up roof, the writers found the insulation to be the most controversial. The controversy stems, perhaps, from the fact that the majority of research, development and promotion in the roofing materials industry seems to be related to the insulation, rather than the asphalt, felt, or flashing.

The ideal insulation could be said to have the following properties:

1. Rot proof.
2. Incombustible.
3. Resistant to deterioration when exposed to heat or sunlight.
4. Ability to resist moisture and asphalt absorbtion.
5. Low permeability.
6. Low coefficient of thermal expansion.
7. Reasonably light in weight.
8. Good compressive, tensile, shear, flexural and indentation strengths.
9. Ability to resist warping.

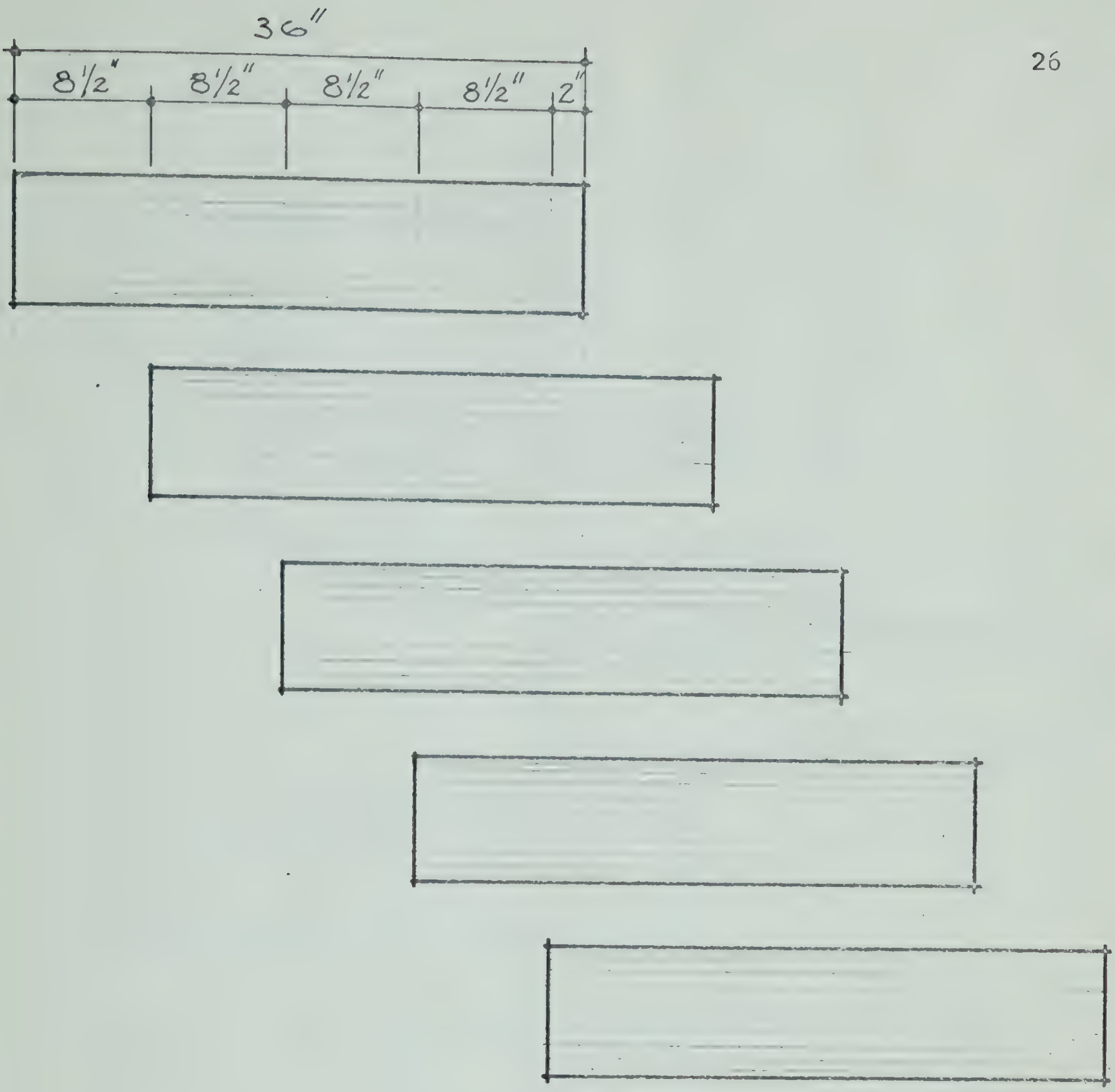

FIG. 3

4 PLY - REGULAR

ROOFING FELT LAYING PATTERN

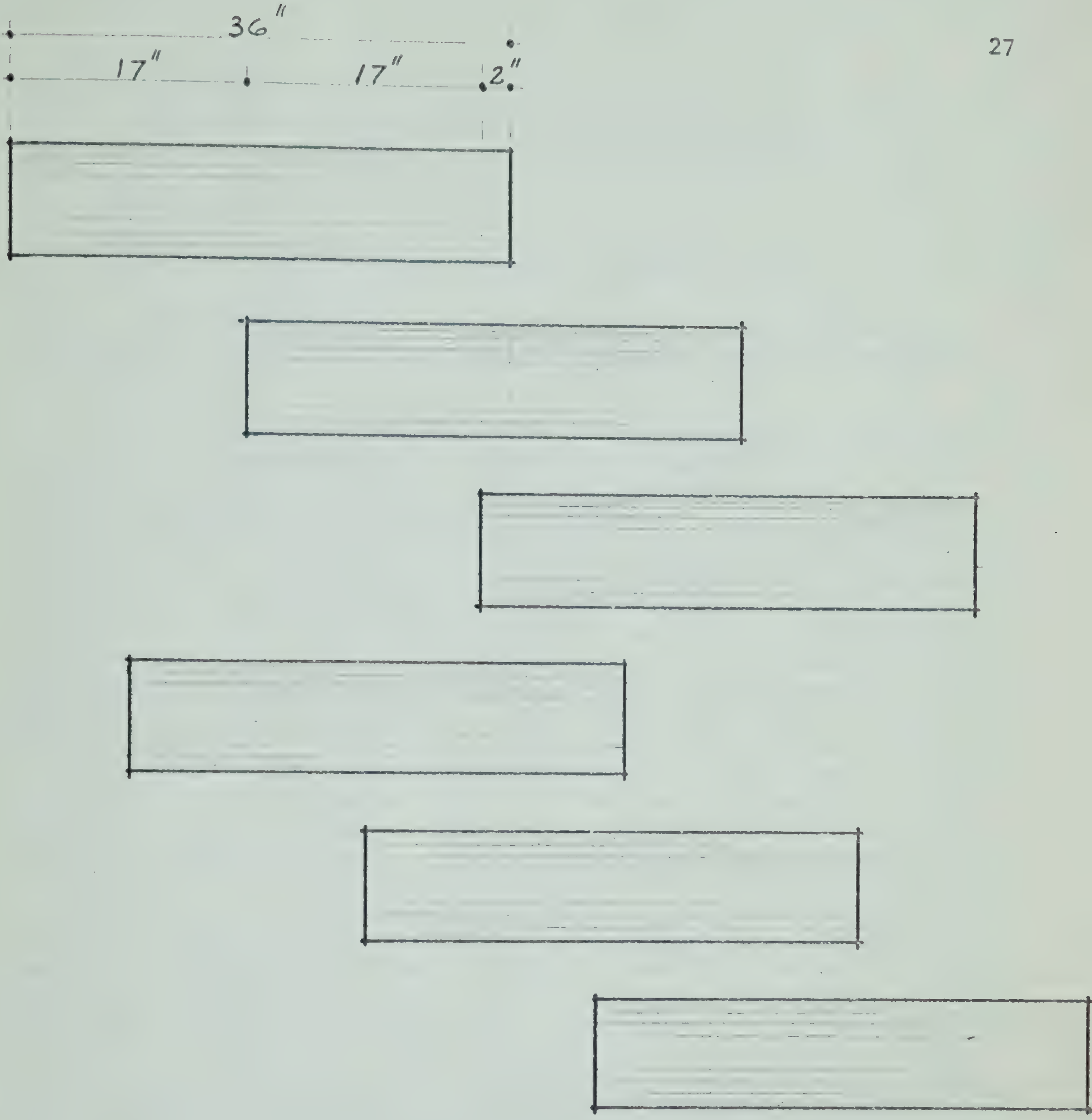

FIG. 4

4 PLY - TWO ON TWO

ROOFING FELT LAYING PATTERN

10. Not easily damaged during transit and installation, but easy to install.

11. Low "k" value.

12. Uniform dimensions of pieces as manufactured.

Unfortunately, there are no roof insulations on the market which have all of these properties, although some appear to approach the ideal material.

Insulation is a material which is easily damaged. Its insulation value can most readily be decreased by allowing it to take on moisture. By its nature then, insulation, particularly the rigid board types used for roofs, must be transported, stored and applied very carefully. Some types of insulation are more sensitive than others to lack of care given to them during transportation, storage and application. It is reasonable to conclude that an excellent product (as determined under laboratory conditions) may lose its excellence by improper handling. How much should be expected of a builder in the way of care to be taken? This is a question which the designer must ask himself, not only with regard to insulation but with regard to many building materials. A reasonable conclusion to be drawn is, should the product appear to be quite acceptable under ideal conditions, but also appear to require an unusual amount of "policing" on the job, the product is not particularly suitable for use in some areas of today's general construction industry. Field conditions in Alberta climates are far removed from controlled laboratory conditions. Before an insulation is specified, it is important that a definite assessment of the probability of near-laboratory conditions being duplicated in the field be made. Very often an excellent product, as shown by a laboratory test, is found by experience to require too much "care" in the field -- if it is actually given the required "care", the cost of its use may be excessive -- if the product does not get the required "care" (too much reliance being placed on rigid specifications being adhered to), the cost of the installation may be in line with the estimated cost but the performance of the product will be found to be far below that which is expected and that which is claimed by the manufacturer.

The argument has been often presented, that an insulation should be capable of resisting deterioration should it become wet, and that if an "inert" type of roof insulation is used, difficulties as a result of wetting would not arise. If this argument is to be upheld, then Stramit, wood fiberboard and Fiberglas are not suitable as roof insulations. Certainly some insulations are more capable of withstanding the detrimental effects of being water-soaked than are others but it must be remembered that any insulation which will absorb water loses most of its insulating property. If we are willing to settle for a wet insulation which doesn't deteriorate, then we should consider deleting the insulation entirely. Those insulations which are not affected by water are generally affected by uneven heating, and if they are not 100% anchored

PRODUCT	WT/FT³ (OVEN DRY)	WT/FT²/IN THICK	R-MANUFACTURER *	R-ASHRAE @ 75°F	COEFFICIENT OF EXP. PER 100°F	PERM-IN VAP. P. TEST *	MOISTURE ABSORPTION – % VOLUME IN 2 HRS.	COMPRESSIVE STRENGTH	BUTT OR LAP JOINT	THICKNESS AVAILABLE	SHEET SIZE	COMBUSTABLE, NON-COMBUSTABLE OR FIRE RETARDANT	COEFFICIENT OF EXP. (IN/IN.) R.H.-40% to 90%	FEELING UNDER FOOT
VERMICULITE (1:6)	26	2.2	0.70	0.8	0.00048	?	?	NO UNIFORM TEST ESTABLISHED	—	—	—	N.C.	?	FIRM
STRAMIT STRUCTURAL (ROOF)	—	3.6# FOR 2"	0.43	NOT LISTED	LOW	?	6.3		B	2" ONLY	4'x8'	F.R.	0.002 LENGTH 0.001 WIDTH	FIRM
MINERAL BOARD (FESCO)	11.0	1.0	0.36	0.36	LOW	30	4.1		B	3/4", 1", 1 1/4", 1 1/2", 1 3/4" 2", 2 1/4", 2 1/2", 2 3/4", 3"	2'x4'	F.R.	0.002 LENGTH 0.001 WIDTH	FIRM
J.M. WOOD FIBER BOARD		1.3	0.36	0.36	LOW	?	?		L	1/2", 1", 1 1/2", 2", 2 1/2", 3"	2'x4'	C	?	FIRM
B.P. WOOD FIBER BOARD (PLAIN WHITE)	18.0	1.5	0.33	0.36	LOW	31	32		L	1/2", 3/4", 1", 1 1/2" & 2" STOCKED – OTHERS ON REQ.	2'x4'	C	?	FIRM
STRAMIT INSULATION (ROOF)	—	3.0# FOR 2"	0.33	NOT LISTED	LOW	?	6.3		B	2" ONLY	4'x5'	F.R.	0.002 LENGTH 0.001 WIDTH	FIRM
FIBROUS GLASS (FIBERGLAS)	9 to 12.0	1.1	0.27	0.25	?	?	27		B	1/2", 3/4", 1", 1 1/8", 1 1/2", 2"	3'x4'	N.C.	?	SPONGY
FOAMED POLYSTYRENE (ROOFMATE)	1.9 to 2.5	0.2	0.20	0.26	0.0040	0.4	0.25		B	3/4", 1", 1 1/8", 1 1/2", 2"	2'x4'	F.R.	O	FIRM
FOAMED POLYURETHANE (VIKING)	2		0.12	0.17	0.0035	0.4	LOW		B	1/2", 5/8", 3/4", 1", 1 1/2", 2"	16"x4' 2'x4' 3'x4'	F.R.	O	FIRM
FOAMED GLASS	11.0	1.0	0.38	0.40	0.00046	0.04	0.9		B	1"	2'x4'	N.C.	O	HARD
GLASS BEAD (P.C. CELRAMIC)	11.0	1.0	0.38	0.39	LOW	LOW	LOW	—	B	1"	2'x4'	N.C.	O	HARD
PERLITE (1:6)	26	2.2	0.59	0.8	LOW	?	?		—	—	—	N.C.	?	HARD
CORK BOARD	7	0.6	0.27	0.27	?	2.5	?		B	?	?	F.R.	?	FIRM

* TEST PROCEDURES (T & R.H.) NOT CONSISTENT

FIG. 5

to the substrate, will bow, cup or crack. The limitations of the insulating material being used must be recognized, both by the designer and the builder, and the material must not be expected to perform beyond these limitations.

The roofing insulations (designed to be applied on top of the deck), which are most commonly used in Alberta today are:

1. Wood fiberboard

2. Glass fiberboard (Fiberglas)

3. Straw board (Stramit)

4. Foamed Polystyrene board (Roofmate)

5. Mineral board (Fesco)

6. Vermiculite C.I.P. (Zonolite)

Other insulations which are generally available, but for various reasons are not used to any great extent are:

1. Foamed Polyurethane board

2. Foamed Glass board

3. Perlite Bead board

4. Glass Bead board

5. Cork board

6. Gypsum board

Wood fiberboard is the "old standby" insulation, and the major Alberta producer is Building Products Ltd., Wabamun plant. Johns-Mannville manufactures wood fiberboard in Eastern Canada but this material is not imported to Alberta. Building Products Ltd. manufacture the J-M wood fiberboard used in Alberta. Wood fiberboard, plain white or asphalt impregnated, will rot under continuing damp conditions. It is absorbtive to both water and asphalt. Poorly manufactured material will delaminate. Dominion Bureau of Statistics figures indicate that domestic shipments of wood fiberboard, on a ½ inch thick basis, exceeded 200,000,000 square feet in 1965 for Canada, and 20,000,000 square feet for Alberta.

Glass fiberboard rigid roof insulation is produced in Alberta by Fiberglas of Canada Ltd. This product is composed of glass fiber held together by a chemical binder. The top face and ends of the

board are covered with an asphaltic paper.

Page 31, second paragraph: The first and second sentences should read:

_ _ _ _ _ _ _ _ _ _ _ manufactured in Alberta by the Stramit Corporation Ltd. for about 14 years. The plant, established _ _ _ _ _ _ _ _ _ _ _ .

1967). The treated straw is compressed and bound under pressure and heat between sheets of heavy kraft paper. It is available with or without a vinyl covering on one face. Stramit roof board is manufactured in four structural deck grades and an insulation grade. The average yearly production of Stramit in Alberta is over 2,000,000 square feet of 2 inch thick material. The total area of Stramit in Alberta Government roofs to date is approximately 2,000,000 square feet. The material has been used on Homes for the Aged roofs on about 60 sites, and on approximately 40 other Government Buildings.

Stramit will warp slightly if wetted and dried on one face only, or if exposed to the sun on one face only. The sheets are water resistant unless the paper covering is broken. Up until the spring of 1967, only the straw at the paper-straw interface was treated for rot, however, now the entire straw content is rot-proofed. Research is presently being carried out to further improve the fire-rating of the material. The major complaint about Stramit roof insulation and deck, as voiced by those people interviewed, was that it deteriorated rapidly upon becoming and remaining wet.

The best application of Stramit is when, as a structural deck, it is nailed to wood joists, with the underside of the Stramit exposed to the interior of the building, or when applied over a fluted metal deck. If humidity could be high within the building (and this is a possibility which must be considered as probable) a vinyl-covered Stramit should be used, the vinyl covering being on the underside only.

Satin galvanized 1 x 3/4" metal tees and L's are used at end joints, both for support of sheet ends and confinement of caulking gum.

Sheets should be layed with the length parallel to the joists and

Page 31, paragraph seven: The first sentence should read:

_ _ _ _ _ _ _ _ _ _ _ 16" OC (on center).

have been found by job inspection to be tight, however, joints between the sheet ends have been found to average ¼", with some joints being ½" in width. These wide joints are not troublesome, as long as they are caulked (usually with asbestos-fiber roofing gum).

Caulking of the joints provides the necessary seal to prevent migration of moisture from the building exterior to the underside of the felts. The caulked joint also provides a base for the first coat of asphalt, to assure complete coating of the underside of rag felts. In the case of glass felts being used over the Stramit, it is recommended that 6" wide

board are covered with an asphaltic paper.

Stramit insulating boards have been manufactured in Alberta by the Stramit Corporation Ltd. For about 14 years the plant, established in 1953, was the first of its kind in North America.

Stramit is composed of grain straw, treated for rot (as of Spring 1967). The treated straw is compressed and bound under pressure and heat between sheets of heavy kraft paper. It is available with or without a vinyl covering on one face. Stramit roof board is manufactured in four structural deck grades and an insulation grade. The average yearly production of Stramit in Alberta is over 2,000,000 square feet of 2 inch thick material. The total area of Stramit in Alberta Government roofs to date is approximately 2,000,000 square feet. The material has been used on Homes for the Aged roofs on about 60 sites, and on approximately 40 other Government Buildings.

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Satin galvanized 1 x 3/4" metal tees and L's are used at end joints, both for support of sheet ends and confinement of caulking gum.

Sheets should be layed with the length parallel to the joists and nailed to the joists with 3½" coated nailes at 8" OC (edges) and 16" OC (centre). Stramit is strongest flexurally in the short direction (perpendicular to direction of extrusion). All sheets job-cut should be taped on the cut ends using 5" masking tape. Joints between the long edges have been found by job inspection to be tight, however, joints between the sheet ends have been found to average ¼", with some joints being ½" in width. These wide joints are not troublesome, as long as they are caulked (usually with asbestos-fiber roofing gum).

Caulking of the joints provides the necessary seal to prevent migration of moisture from the building exterior to the underside of the felts. The caulked joint also provides a base for the first coat of asphalt, to assure complete coating of the underside of rag felts. In the case of glass felts being used over the Stramit, it is recommended that 6" wide

Fiberglass tape be used, solid mopped in hot asphalt, in addition to the caulking, to provide extra strength at the joints and to provide a base on which the glass felts can rest. It is essential that glass felts be supported 100%, otherwise, the asphalt will bleed through the felts and then leak water. For the exposed soffit application, the gum must be used to prevent asphalt, applied when the felts are being layed, from leaking between the joints and marring the soffit.

Stramit does not absorb hot asphalt, as do some wood fiber insulation boards, and provides an excellent base for assuring positive bond of felts.

Even though nail heads lie directly under the roof membrane, the cold bridges formed are not critical, as the nails are driven into wood joists. It is not likely that Stramit would be nailed over a wood deck, so the problem of frost build-up on nail points projecting to the interior of the building will not arise.

Stramit insulation board, when used over a metal deck, is an acceptable application. Stramit may be anchored directly to the deck through the use of a cold applied fire rated adhesive; however, a fire retardent vapour barrier is recommended to go directly on the metal deck. Metal deck cannot be considered a vapour barrier because of the many joints in the completed deck assembly. The Stramit can then be layed in adhesive applied over the vapour barrier.

There have arisen many problems in the past through the use of Stramit. When the manufacturing of Stramit was started in Alberta, there was difficulty in maintaining uniform density of board and difficulty in removing all grain and weed seed from the straw. The product has been improved steadily, and today it is, in the writer's opinion, an excellent building, <u>when used properly within its limitations</u>. The manufacturer continues to employ scientific organizations to test the product and look for further possible improvements. The three prominent failures of roofs on Government building projects which utilize Stramit are School for the Deaf, Terrace Building and various Homes for the Aged, all of which have been studied. In all cases the failures could not be attributed directly to the Stramit, but to faulty design or faulty workmanship which resulted in the Stramit becoming wet (Refer to VI (a)).

Polystyrene has been used as an insulating material for some time. Through the promotion of a wall insulating material for use as a roof insulating material, polystyrene insulation acquired a poor reputation. Polystyrene bead-board wall insulation did not prove satisfactory as a roof insulator because of its softness, dimensional instability and absorbtive surfaces. Regular foamed polystyrene insulations, too, proved generally unsatisfactory as roof insulators because of their having these same properties. Roofmate is a particular type of polystyrene insulation manufactured specifically for use in built-up roofs. It is manufactured in Ontario by Dow Chemical of Canada Limited. Roofmate was introduced into Alberta around 1960. Up to 1965, approximately 1,000,000 square feet of roof area on approximately 75 Alberta projects has been insulated with Roofmate. Since 1965, Alberta usage appears to be approaching 1,000,000 square feet per year.

Roofmate is inorganic and will not rot. It is a closed cell product, and is described by the manufacturers as being impervious to the passage of moisture. The process used in the manufacture of Roofmate results in a denser board with "slick" surfaces. It will melt at the temperatures of hot asphalt, and will deteriorate rapidly if exposed to sunlight. It has a relatively high coefficient of thermal expansion, and this property must be recognized in any design utilizing Roofmate.

The National Research Council, Division of Building Research, Saskatoon, is presently engaged in researching the practicability of installing the roof insulation over the membrane. A large building in Prince Albert, Saskatchewan with a roof area of about 7,000 squares, is to be constructed shortly, employing the insulation-over-membrane system. The insulation is Roofmate and as far as the writers know, this polystyrene material will be bedded in warm asphalt, the top surface painted to protect it from the effects of solar radiation and then covered with gravel. In theory, this system should work well; it is simply a new approach to an old system - keep the roof membrane and the substrate to which it is affixed at as close to the same temperature as is possible and allow the insulation to "breathe" to the cold side. With the rapid development of new inorganic and fairly inert materials, this system of insulating over the membrane may well replace the present system of membraning over the insulation.

It is the writers' opinion that a gravel layer applied directly over the Roofmate may result in some problems. Loose gravel could be blown off of the roof by high winds. The gravelling operation could lead to extensive damage to the insulation, through the breaking open of the paint protection. Isolated pieces of insulation which might be poorly adhered to the membrane would not gain any resistance to uplift from a continuous overall covering. It would seem that if the Roofmate were covered with thin precast concrete slabs, say 2 ft. square and 1½" thick, each weighing about 75 lbs., many advantages would be gained. The roof surface would be reflective, resistant to the weather and resistant to mechanical damage both during and after construction. The weight of the slabs would be sufficient to resist wind uplift. There would be some tendency toward "slab excursion", but this problem should not be difficult to rectify.

Fesco mineral board is a product consisting primarily of pearlite granules held together in a fire resistant matrix of mineral fibers and binders. In appearance, it is similar to asphalt impregnated wood fiberboard. Fesco board is manufactured by Johns-Mannville in the United States. It is possible that a plant may be established in Canada within the next year or so. Fesco board is a comparatively strong material, described by the manufacturer as being resistant to rot and deterioration by wetting. It is precoated on one surface to prevent absorbtion of asphalt.

Foamed polyurethane is manufactured in Canada by Viking Laminates Ltd. of Winnipeg. This material is a rigid foam self-bonded to polyethylene

coated paper facings. Foamed polyurethane has the lowest "k" value of any of the readily available insulations. It has a rather high coefficient of thermal expansion; its performance at roof-top temperatures over a period of time, considering the chemical nature of the material should be further investigated. From the manufacturers description of foamed polyurethane, it appears to be an acceptable roof insulation.

Vermiculite is the technical name for a type of mica. "Zonolite" brand of vermiculite is an expanded mica, which, amongst its many applications, is used as a lightweight aggregate in the manufacture of Zonolite insulating concrete. Zonolite insulating concrete has been widely used for many years in Alberta as a combined structural and insulating roof deck. Zonolite concrete is mixed using approximately three times the amount of water as is used for normal concrete. It is very 'soupy' when being placed and cannot be slope-screeded until it has stiffened somewhat after placing. Zonolite concrete is rot-proof and incombustible. It will absorb a considerable weight of water, and is permeable. The material is quite soft, and has little strength in tension. The application of a roof membrane over Zonolite insulating concrete, in the writers' opinion, is a touchy operation. Exceptional care must be taken with design details, when the material is to be used over a solid concrete surface. The manufacturer recommends the use of vents to control blistering (Photo #92 & 95). From an aesthetic viewpoint, these vents are not particularly desirable.

Insulation is most often thought of with regard to its prime function, and that is its ability to resist the passage of heat. A measure of the insulating value of an insulation is its "k" factor. The "k" factor is a term which expresses the number of British Thermal Units (B.T.U.) which will pass through a square foot area of a one-inch thickness of a singular material in one hour, with the air on one side of the test piece being generally at 75° F. There are several ways in which "k" can be established. The most widely accepted test procedure is that which is outlined in A.S.T.M. Specification, known as the Guarded Hot-Plate method.

Since all design calculations and the thickness of insulation required are based on this "k" factor, it is most important that "k" is determined, for all materials being compared, using identical test procedures. If identical (or very nearly so) procedures are not used, the resulting "k" values are not truly comparative, hence a true comparision of the insulating values of insulation materials is not possible.

Figure #5 shows a comparison of various properties of roof insulations. The values for "k" are shown to the second decimal place. The writers feel there must be some doubt as to the accuracy of this second decimal place. Far too much argument has developed in the past between manufacturers and designers regarding the insulating values of insulations of various makes. It must be remembered that the "k" values published are obtained in the laboratory with perfectly dry specimens. No data are made available by manufacturers regarding the "k" values of their product at varying moisture contents, however, it

has been reported that some insulations can lose over 60% of their insulating value when wet. The dryness of insulations will vary in different climates and under varying conditions of storage and weather. The insulating values of different types of insulations are affected through varying degrees by moisture. What, then, is the "k" value of the insulation at the time of application, and what is it likely to be a year from that time? Considering this question, the designer should probably be concerned more with the probable field "k" than the laboratory "k".

It is the writers' opinion that the designers should state, in the project specifications, the thicknesses of acceptable insulations considered as having equal "C" values. A table of thickness is contained in the recommendations outlined in Section X of this report.

Insulation to be used in a built-up roof should have reasonable dimensional stability. Those that have large coefficients of thermal expansion must be well secured to the substrate, so that expansion, contraction, cupping and bowing are restrained. The opening and closing of joints in an insulation installation will certainly lead to premature failure of the membrane, unless there is adequate unbonded width of membrane on either side of the joint. This condition is impractical to obtain in the field. In order to achieve a continuous "plate" of insulation, it is felt that the insulation should be applied in two layers, with the joints in the top layer offset from those in the bottom layer. It does not go unnoted that this recommendation might lead to hardship for some manufacturers, if the insulation specified by the designer is minimal.

There has been much discussion regarding the relative merits of lap joint insulations and butt joint insulations. The lap joint is designed primarily to assist in providing a continuous "plate", and to reduce heat loss. It is felt that a two-layer application results in both of these advantages being obtained, but to a much higher degree. It is recommended that all rigid board insulations be specified to have butt joints and be layed in two layers. The butt joint material has been found, generally, easier to install than the lap joint material.

Many people interviewed were asked by the writers "why are insulation joints staggered, and why generally in one direction only?" No answers were obtained other than one to the second question which indicated it was impractical to install the end-of-day's-work cutoff in a saw tooth pattern. Roofing contractors and insulation manufacturers seemed to have only vague ideas as to why the insulation laying patterns have evolved as they have.

This subject of the pattern of laying insulation could be discussed at some length. The writers, after having examined what might be the effects of the membrane of varying the insulation laying pattern, have been unable to conclude that there is any great significance to the pattern in which insulation might be layed. It is suggested that a two layer application of insulation layed with the joints of each layer in line in

both directions will perform satisfactorily.

Since the top surface of an insulation receives a field coat of hot asphalt, it must resist the absorbtion of this asphalt layer left to bind the roofing felts to the insulation. The absorbtion must be resisted at the time of application, and for the life of the built-up roof. A high S.P. asphalt coating, factory applied, should substantially eliminate excessive absorbtion of asphalt into wood fiberboard. The asphalt coating need be applied to only one face of the sheet. The coated face must be positioned during installation as the top face.

There seems to be no valid reason for the continued use of asphalt impregnated wood fiberboard. No advantage is obtained for the extra cost of this material (about 1½¢ per square foot for 2 inch total thickness). In comparison the cost of an asphalt coating has been estimated by one manufacturer to be slightly less than the cost of asphalt impregnation.

The primary reason for taping the joints of an insulation over which rag felt is to be placed is to assure a continuous coating of asphalt to the underside of the first felts layed. The primary reason for taping the joints of insulation over which glass felts are to be placed is to prevent the bleeding of the asphalt from the felt into the joint. A dry strip of rag felt will not bleed, but it is susceptible to wetting. This wetting may cause swelling of the felt, and result in buckling of the membrane. On drying, the felt may shrink and split. A glass felt is quite porous when bled of asphalt, and with a wide joint between insulation pieces it is only a matter of time before a leak in the membrane will develop over this joint. Proper fitting of insulation is necessary if the membrane is to perform properly. From a practical viewpoint, proper fitting is difficult to control in the field. Taping eliminates the need for precision of a degree incompatible with the operation being carried out.

Taping is done using, most generally, either a 5-inch wide masking tape, or a 6-inch wide kraft paper tape. The paper tape is composed of two thin sheets of paper between which glass strands are imbedded in a bituminous material. The masking tape is simply pressed down over the joints (it is self adhering), whereas the paper tape is applied in a mopped strip of hot asphalt. In either case, there is little value in the taping if it is not done properly. (See Photo #30). Taping, then, not only assists in preventing membrane wetting, but also assists in restraining the movements of insulation at the joints. Taping further provides an additional ply of membrane over the joints, thus strengthening the membrane along joint lines (Ref. #18). The cost of taping an insulation in 3 feet by 4 feet pieces is about 2¢ per square foot of roof area.

With a single layer application of insulation, the argument for taping all joints appears quite valid for the reasons noted above. If insulation is installed in two layers, however, the additional joint-strength argument is no longer pertinent. For the small cost involved, however, it might be well to tape all board insulations, except Roofmate.

Roofmate is installed with a base sheet which performs the same function as would tape.

A two-layer application of insulation to any thickness less than 4 inches is quite practical when considering wood fiberboard, Fesco board and rigid fiberglass. Roofmate is manufactured to a minimum 3/4 inch thickness and since two thicknesses of this material totalling 1½ inches has a "C" factor lower than generally called for, Roofmate would have to be produced in a 5/8 inch thickness to meet a two-layer application with a "C" factor of 0.16. A total thickness of Roofmate of 1¼ inch has a "C" factor of 0.16. Stramit is manufactured in one thickness only (2 inches) and a double layer of Stramit would result in a "C" factor much lower than required.

In the field, insulation was seldom seen properly stored. From what the writers saw, the roofing contractors appear to be prone to taking far too many chances with the weather. It could be stretching a point to assume that contractors discard all material which has become slightly wet through lack of protection from the elements. Proper protection is a must, and should be strictly enforced.

Design details often make the proper installation of insulation next to impossible. Conduits run tight against the roof deck invite trouble (Photos #61 & 67), unless an extra thickness of insulation is specified for the entire roof area. Designers must think out in more detail the installation of the roofing system being called for and not leave so many of the so called "little problems", to be solved by the roofer. Designers should spend time observing the roofing operation and learn to appreciate the difficulties with which a roofer must contend.

During the many interviews, cutoffs were discussed at length, and the writers found a definite division of opinion of their use. A water cutoff is simply one or two plies of felt, about 16 inches wide, mopped in place over the edge of the roof insulation. The felts extend from the top of the insulation to the top of the deck, and form a barrier to the sideways penetration of water into the insulation. At the end of a day's work it is essential that this cutoff be installed. It should be removed, however, the next day, prior to the continuation of roofing operations. The general idea behind built-in cutoffs is the dividing up of the insulation into sections. Each section theoretically becomes a watertight basin and should a leak develop in the membrane, the water entering the section is retained within the section, and the damage to the roofing is then confined to a relatively small area.

Cutoffs are difficult to install properly. If the felts are not pushed absolutely tight against the edge of the insulation, the next piece of insulation cannot be installed without an overly wide joint being left between pieces. (Photo #31). If the cutoff locations are not in some way identified either on a plan in the janitor's office (is it an as-built drawing, and will it be available ten years hence?), or by markings on the parapet flashings, a lot of roof might be torn up unnecessarily while the

repair crews are trying to locate the isolated area. Then, too, the cut-off is impractical unless the insulation is installed with joints in line each direction.

In theory, interior cutoffs appear to be a desirable feature in a built-up roof. It is felt by the writers, however, that more problems are created than are solved through their use. Edge cutoffs on the other hand are considered essential (Photos #74 to 78). These are easier to install since there is only one insulation edge involved in the detail. Over this edge are generally installed two or three plies of felt, to reinforce the membrane at the cant strip bend, and this reinforcement serves also to reinforce the cutoff line. Edge cutoffs should be installed, not only at roof edges, but also at all other projections above roof level Every projection penetrating the roofing membrane is a potential leak and must be treated carefully.

(e) Flashings

Difficulties with a built-up roof will most certainly occur if the designer fails to appreciate the details required to render a completely waterproof roofing system. The role that flashings play in the maintaining of this system waterproof is a most important one.

The four most commonly used flashing materials are light gauge galvanized iron, 16 oz. copper, aluminum and heavy mineral coated asphalt roofing felt. The properties of the metal flashing materials are shown in Fig. #1. Of these four materials, either galvanized iron or copper is generally specified. Because of the multiplicity of flashing designs produced, it is impossible to give a definite price to cover flashing in general, however, for an "average" flashing, copper costs about $1.50 per square foot.

Copper flashing has been used frequently on Government projects. The reason for this usage are not certain, but it would seem that expected appearance must be the principle one. The disadvantages of using copper are: (a) high coefficient of thermal expansion, (b) streak-staining of building walls, (c) high cost. Copper may last for many more years than galvanized iron, however, galvanized iron will last as long as will the built-up roof. A material that lasts longer than this is unnecessary. Galvanized iron can be painted if the silvery finish is not aesthetically acceptable. On a building such as the Terrace Building or the School for the Deaf, the difference in cost between using copper flashings and galvanized iron flashings would amount to approximately $0.25 per square foot of roof area, or $25.00 per square. Considering the 500 square area of the Terrace Building roof, the extra cost for copper flashing was approximately $10,000.

Flashings, if properly designed, should shed water and not hold it. This is the same basic principle which is applicable to the roof membrane. A flashing, most generally, protects certain critical areas of the roofing membrane from rapid deterioration. The upturned membrane at parapets, curbs, control joints and other roof projections, will lose

it's asphalt in time if not protected from sun and rain. As a general rule it is not wise to consider the flashing as a watertight covering. For this reason it is necessary to cover the top and inside faces of roof curbs and parapet walls with a waterproof material. A heavy base sheet or the roofing membrane should be used to perform this function.

Base flashings can often be seen mopped and gravelled into the roofing membrane (Photo #133). This procedure results in the joining of two materials of quite different physical properties. The base flashing should rest on top of the gravelled membrane and not be built into it. (Photo #56A). The building - in of the base flashing also prevents the escape of water from behind the flashing. This trapped water will usually find its way into the roofing "sandwich".

The exterior caulking of flashing joints has been found by the writers to be practiced quite commonly. (Photos #128,143,147). Attempts were made to repair leaky flashings on the Terrace Building using a silicone type of sealant, however, even this material did not resist the combined effects of flashing movement and solar radiation. (Photo #120).

About half of the flashings on the N.A.I.T. and the School for the Deaf are also caulked. This caulking is a visual admission that either the roof membrane does not exist beneath the flashing, or that the membrane, if installed, was poorly installed and leaks. The two joint types best suited for flashing details are the "S" bend and the upstanding seam.

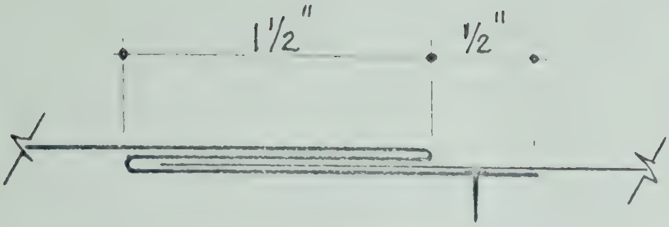
Whenever a masonry coping is used to cap a parapet, through-wall flashing must be used. The mortar joints in the coping cannot be relied upon to remain watertight.

Many designers specify 26 ga. galvanized iron flashing for all flashing details. This material is adequately stiff when fabricated to a reasonable girth, however, for girths over 12" some designers and fabricators considered it too light. Galvanized iron of 24 guage is more suitable material to use for girths over 12". Designers should take into account, whenever possible, the stock sizes of sheet metal. Most light guage galvanized iron is readily available in the standard 8 foot length, and in widths of 30 inches and 36 inches. Lengths of 10 feet and widths of 48 inches are not always readily obtainable in small quantities. It is not difficult to imagine that a contractor might be tempted to "cut corners" on flashing if the total width of sheet required for a particular detail is 38 inches.

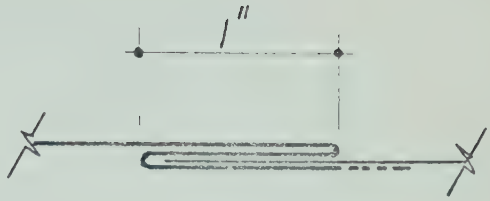
It is suggested that some time be spent by designers and administrators on the roof of the Terrace Building and the flashing details examined, for just about every example of good and bad flashing can be seen. Both copper and galvanized iron have been used for flashings. Most of the copper is reasonable in appearance, but some is badly corroded. Stains can be seen on the west face of "C" block, just below the copper flashing although the wall has been just recently repainted. Some of the new flashings installed are painted galvanized iron. There are cap

flashings with sloped tops and flat tops, "S" bend seams, plain lap joints and standing seams. There are many cap flashings with drip legs only 3/4" long-they should be at least 4½". Some seams are externally caulked but most of this caulking is now unbonded to one side of the joint. Base flashings are both free of the membrane, as they should be, and built into the membrane. In all probability, the leak problems with the roof of the Terrace Building will continue to develop.

Some time should also be spent examining the roof of the N.A.I.T. All manner of poor flashing details can be studied on this building. Once seen, they are not likely to be repeated by those seeing them.



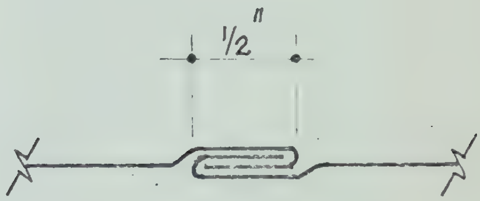
PROPER DETAIL



POOR PRACTICE

"S" BEND FLASHING JOINTS

PROPER DETAIL



SHORT STANDING SEAM HAMMERED FLAT TO FORM DOUBLE SEAM--POOR PRACTICE EXCEPT AT MITRED CORNERS

FIG. 6

STANDING SEAM FLASHING JOINTS

FIGURE 7

COSTS

OF

MATERIAL PLUS LABOUR
(Spring, 1967)

Copper flashing 16 oz.	\$1.25 to \$1.50/sq.ft.
Galvanized iron 26 ga.	\$0.30/sq.ft.
24 ga.	\$0.40/sq.ft.
Structural cost to produce roof surfaces sloped to drain.	\$0.10 to \$0.30/sq.ft.
Roofing felt - 4 ply of 15# organic.	\$0.06/sq.ft.
Roofing asphalt for 4 ply of felts.	\$0.04/sq.ft.
Pour coat 50 lbs.	\$0.02/sq.ft.
Gravel 400 lbs.	\$0.02/sq.ft.
Fiberboard, 1½" in 2 layers	\$0.21/sq.ft.

The costs noted above are not exact. Book prices on materials were found to vary considerably from tendered prices. The variation is influenced by the "bidding climate" at the time of tendering. Many suppliers, when asked for prices simply stated, "Our price will be competitive with those of the other bidders; we prefer not to give you a price".

FIGURE 8

COST ANALYSIS OF INSULATED 4 PLY ASPHALT GRAVEL BUILT-UP ROOF

(Spring,1968) (Present General Practise)

	MATERIAL (square)	LABOUR (square)	TOTAL (sq.ft.) (cents)
Felts 4 ply rag 15#	$ 3.50	$ 2.50	6.0
Asphalt 130 lbs.	3.75	2.25	6.0
Gravel 400 lbs.	1.00	1.00	2.0
Cost of Membrane:	$ 8.25	$ 5.75	14.0¢
1" fiberboard (1 layer) non coated-non impregnated	$11.00	$ 1.50	12.50
Asphalt to apply insulation	0.75	0.25	1.00
Add ½" fiberboard	5.50	1.00	6.50
Asphalt for extra ½"	0.75	0.25	1.00
Cost of Insulation:	$18.00	$ 3.00	21.00¢
Concrete deck primer	1.00	0.50	1.50
V.B. - 2 ply rag 15#	1.75	1.00	2.75
Asphalt 35 lbs.(2 layers)	1.00	0.50	1.50
Cost of Vapour Barrier	$ 3.75	$ 2.00	5.75¢
Cost of Built-Up Roof:	$30.00	$10.75	40.75¢

The cost of roofing system composed of -

Gravel and flood coat
4 ply membrane
1½" fiberboard - 2 layers
2 ply vapour barrier
primed deck

is approximately $40.00/sq. or $0.40/sq. ft. Flashings are not included in this figure.

It is emphasized that the quantities of asphalt and gravel shown above are not those that are recommended in this report, but those that were noted as most commonly applied.

V INTERACTION OF STRUCTURAL DECKS AND BUILT-UP ROOFING

The type of material on which a built-up roof is to be layed must be carefully considered in the design of a roofing system. A well designed built-up roof may fail prematurely because it was layed over an unsatisfactory deck.

Concrete decks should be reasonably smooth. Precast concrete units must be assembled so no differential movements take place between units. Adjoining units which do not line up due to slight differences in camber must have the joints between units feathered off with mortar. All decks should be sloped to drain.

Fluted metal decks can cause many problems if they are carelessly installed. The attachment of adjoining units must be positive. A lack of proper support around a hole cut in the deck will result in a roof leak, should someone step on the membrane next to the roof projection (Photo #59). When a fluted metal deck is installed next to the pent-house or tower, the deck must be covered with a rigid material, to allow work to proceed over it. In order to form a combined secondary roof and vapour barrier, this rigid material (3/8" or ½" plywood is suggested) should be firmly affixed to the deck before the secondary roof is applied. The cost of applying a ½" plywood skin over a fluted metal deck is estimated to be about $0.25/sq. ft. The cost of installing a flat top-surface metal deck is estimated at $0.50/sq. ft. more than the cost of the simple fluted deck. Thus the cost of installing a light weight fluted metal deck with a plywood skin is about $0.25 cheaper than the cost of installing the heavier flat top metal deck.

Roof membranes have been applied directly to wood decks for many years, with great success. This success has resulted primarily from designers and builders recognizing the limitations of the materials used. Sheathing boards should not be green or exceed 8" in width, in order that shrinkage movements be minimized. A non-bituminous material should be installed directly over the wood, affixed using nails or staples. A bituminous material may stick to the wood in time, thus impeding the floating action of the membrane. To prevent contact of bituminous materials with the wood deck, a heavy waxed kraft paper is to function as a bond-breaking slip sheet, and is not considered by the writers to be adequate to function as a vapour barrier. In laying a membrane over wood, it is important not only to prevent movement being transmitted to the membrane, but also to prevent the drippage of roofing asphalt through the wood deck. Before the laying of the insulation, a two ply 15# felt vapour barrier or 30# base sheet vapour barrier should be stapled or nailed over the slip sheet.

As has been mentioned previously, the first layer of insulation can be either mopped, nailed or stapled down but the second layer should not be anchored by using nails or staples - it should be applied in a solid mopping of hot asphalt.

Wherever possible, a cant strip should be fastened to the same substrate as is the roof membrane. As an example, the top chords of steel joists on a warehouse roof should be extended to the exterior face of the outside walls of the building to permit the roof deck and cant strip to be fastened to the roof system. The practice of attaching a nailer to the top of the wall, and then running the roof membrane across the joint between the roof system and the wall is certain to result in a tearing apart of the membrane along the wall line.

The apparent coefficients of linear expansion and contraction of asphalt and felt, both in the machine direction (MD) of the felt, and the cross direction (CD) are shown in the following table.

		-60° to 0°	0° to +70°	70° to 140°	-30° to +30°
Asphalt-Organic	MD	18	5	3	11
	CD				21
Asphalt Glass	MD	30	6	3	18
	CD				26
Asphalt-Asbestos	MD	11	6	2	
	CD				
		(a)	(a)	(a)	(b)

(a) Cullen
(b) Jones

FIGURE 9

APPARENT COEFFICIENTS

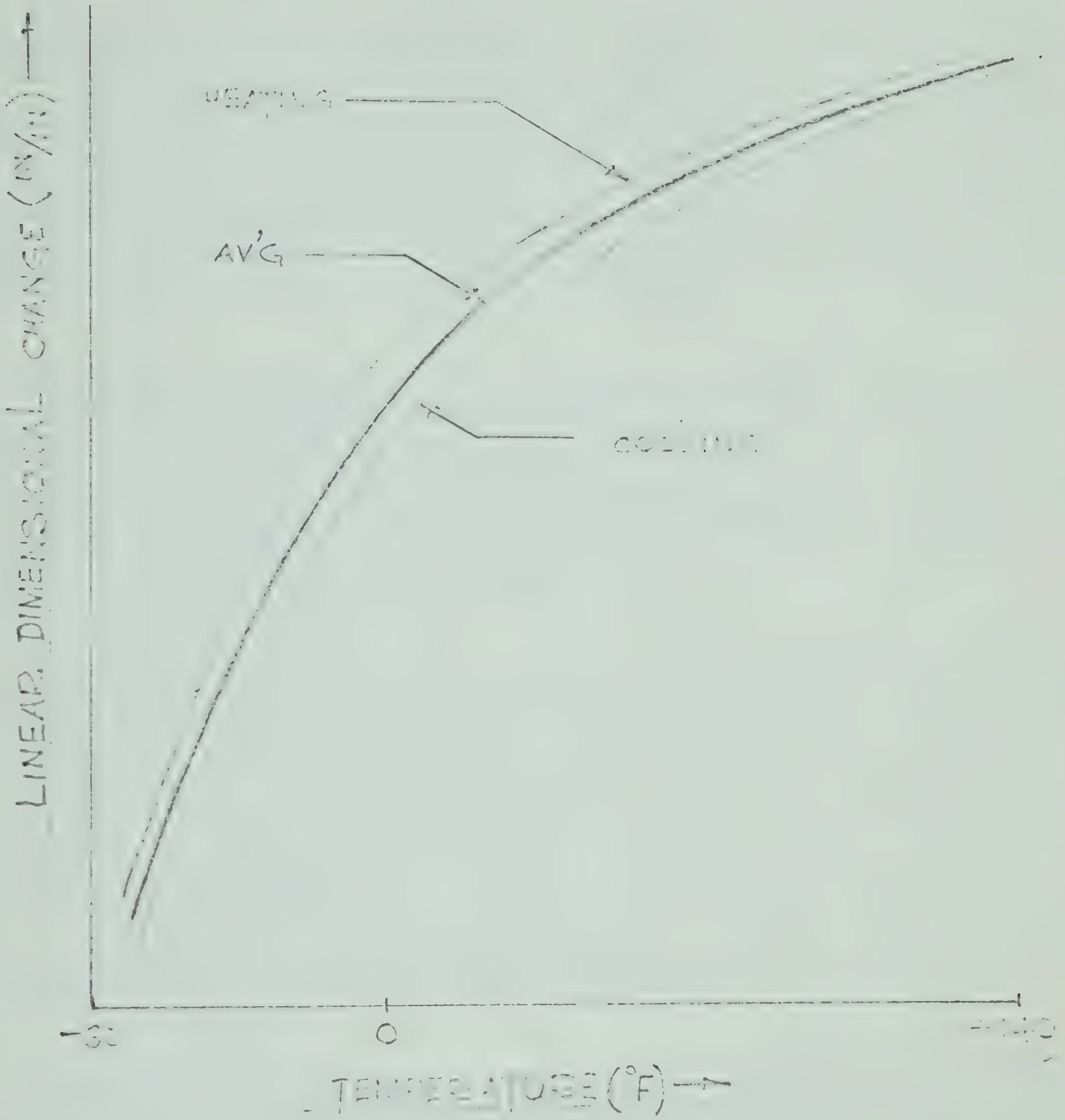
OF LINEAR EXPANSION

in/in/°F x 10^{-6}

The graph shown in Figure #10 illustrates the non-linear relationship between change in dimension and membrane temperature. Note the marked increase in change in dimension at temperatures below zero degrees fahrenheit (Ref. 2,17). This particular point is most pertinent to built-up-roofs constructed in the prairie provinces. Coefficients of expansion-contraction referred to in this report will be those values in the -30°F to +30°F, as reported by Jones.

Asphalt and felt roof membranes, when free to move between widely spaced points of anchorage, have the capacity to resist rather large strains. The breaking load at ultimate strain is, however, relatively small. The average breaking strain of a well constructed membrane is approximately 1% at -20°F. and at +70°F. is approximately 1.5% to 2%. When the rupture strain and the low failure stress are considered, then, it is not difficult to understand why a small crack in the strate to which a membrane is firmly and continuously bonded will very probably

FIGURE 10



General Relationship of

Average Expansion and Contraction of

Built Up Organic and Glass Membranes

(Abridged from Cullen-Ref. 17)

result in a split in the membrane, coincident with the crack in the substrate.

With reference to the discussion on insulations, Section IV (d), a good deal of consideration would have to be given to the method by which the membrane should be affixed to the structural deck. A tightly bonded membrane cannot resist the strain imparted to it through the sudden cracking of a concrete substrate. Since an asphaltic membrane will strain 1% or more before it will rupture, a 1/10" shrinkage crack in the substrate, developing after the membrane is mopped down will quite probably cause the membrane to rupture unless there is at least 10 inches of unbonded membrane over the crack. The rate of strain of the membrane is a most important consideration here.

Peace River Glass Ltd., has developed a perforated base sheet, called "Butnbase". This base sheet is coated on the "down" face with a very coarse grit and contains 5/8" perforations approximately 3" apart. Butnbase is designed to allow differential movement between the substrate and the membrane so membrane ruptures might be minimized. Butnbase further minimizes the localization of high vapour pressure, thus reducing the possibility of blistering of the membrane (Ref. #18).

There is still disagreement amongst researchers as to whether as membrane or vapour barrier should be unbonded or bonded to the substrate. The familiar wood deck - waxed paper - nailed 2 ply 15# felt - 4 ply asphalt and felt membrane system is familiar to most designers. Probably the reason, more than any other, why this type of construction has given so little trouble is that the membrane is"floating"- it is attached to the deck to resist vertical movement, but the method of attachment permits lateral movement and essentially eliminates problems associated with lateral movements. On non-nailable decks, however, intermittent bonding of a membrane can usually be accomplished by channel, strip or sprinkle mopping. The very nature of this type of mopping operation leads the writers to doubt its effectiveness.

The practice of applying the waterproof membrane directly to the insulation tends to promote "thermal shock" in the membrane. This thermal shock results from a great and rapid change in temperature of the membrane with the membrane being restrained from deforming uniformly, by a substrate which remains at a fairly uniform temperature. Complete adhesion to a continuous and rigid substrate can cause the strain to take place uniformly over the membrane, but any differential movement between the membrane and the substrate at joints or cracks can cause high local strains, and result in membrane splitting, stretching or buckling.

In order to maintain uniform stresses in a vapour barrier or membrane, and in order to minimize local vapour pressure build-ups, it certainly seems that intermittent bonding should be a most effective

<u>Page 47, paragraph six</u>: The second sentence should read:

_ _ _ _ _ _ _ _ _ _ _ is the best solution put forth to date.

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In order to maintain uniform stresses in a vapour barrier or membrane, and in order to minimize local vapour pressure build-ups, it certainly seems that intermittent bonding should be a most effective means. The method of accomplishing intermittent bonding is the problem, and the writers feel the Peace River Glass Butnbase approach is the best put forth to date.

VI DESIGN, MATERIALS & WORKMANSHIP RELATED TO POOR PERFORMANCE OR FAILURE

(a) The School for the Deaf, Edmonton

This building is of cast-in-place concrete up to and including the first floor and of precast concrete for the remaining height. The roof is framed with precast concrete girders and double tees. The building is 50 to 60 feet wide and over 900 feet long. Control joints were provided in the foundation walls, the main floor slab, the plaster, block and brick walls, but oddly, no joints were provided in the roof beams or slabs. (Photos #136 & #137).

The original roofing of this building was completed in 1955, and consisted of Stramit insulation layed directly on precast concrete double tees, (no vapour barrier was installed) and was overlayed directly by a five ply 15# rag felt, asphalt and gravel membrane. Flashings were of copper. No control joints in the roof membrane were provided except at the five wings. Parapet flashings were bent to extend horizontally approximately 3" over the top of the parapet blockwork and the parapet was capped with precast concrete capping. The roof is "dead flat". No through-flashing was installed.

Almost the entire roof has been replaced over the last ten years. The reasons for the water penetrating into the insulation and failure of this roof were:

a) no through flashing under parapet coping.

b) no control joints in roofing membrane.

c) no control joints at various roof projections.

d) no metal flashings at changes in roof elevations.

e) installation of wet insulation, and insulation with broken covering.

f) no edge cutoffs installed.

g) no vapour barrier over the concrete deck.

h) excessively rough or uneven deck.

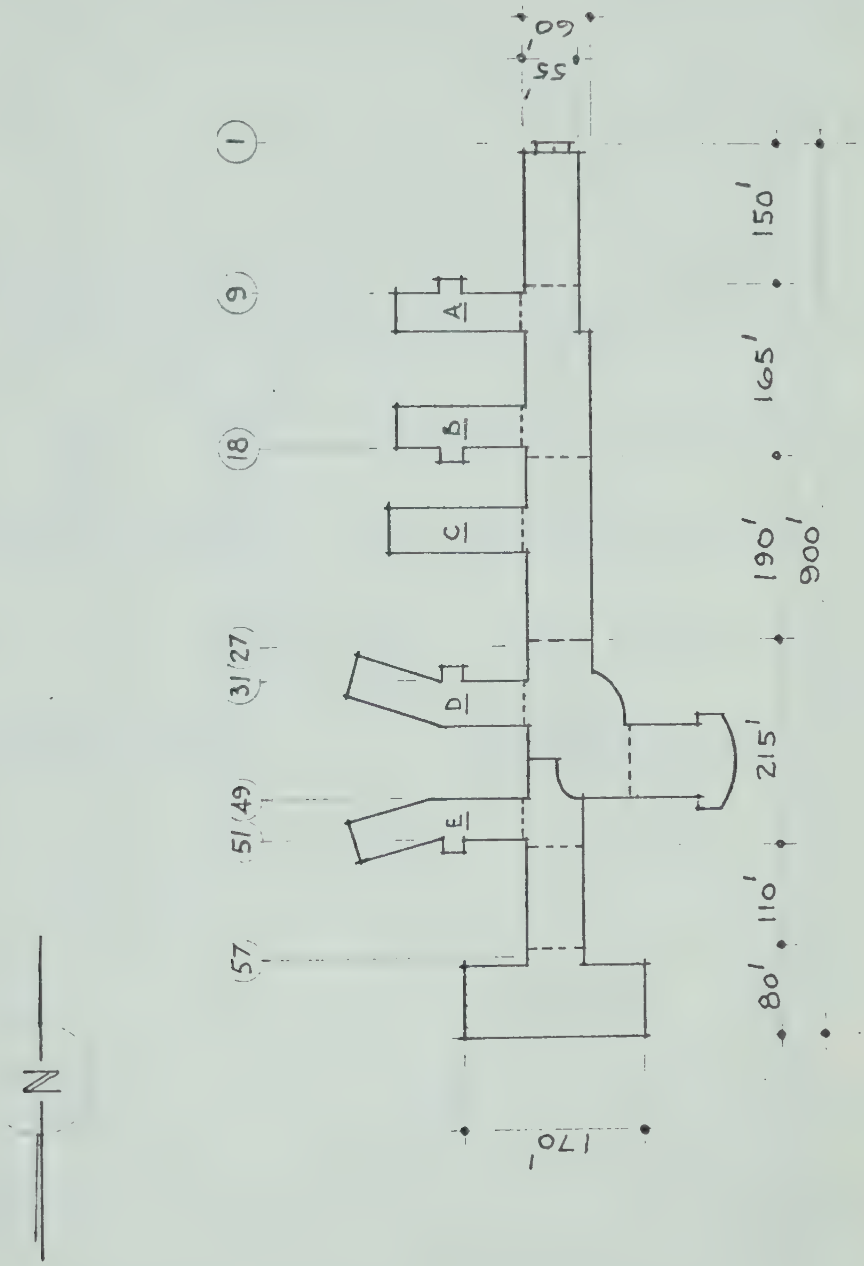
The reroofing program has incorporated the removal of parapet copings, and replacement with sloping cap flashings, the installation of control joints in the roof membrane, and the installation of a vapour barrier. Stramit has been used again on about half of the areas re-roofed and wood fiberboard has been used on the other half.

On the entire roof surface, not one drain can be found on a low area; water can be seen standing in ponds up to 2" deep (Photo #130).

It is the writers' opinion that the roof of the School for the Deaf would have leaked regardless of the insulation which might have been used.

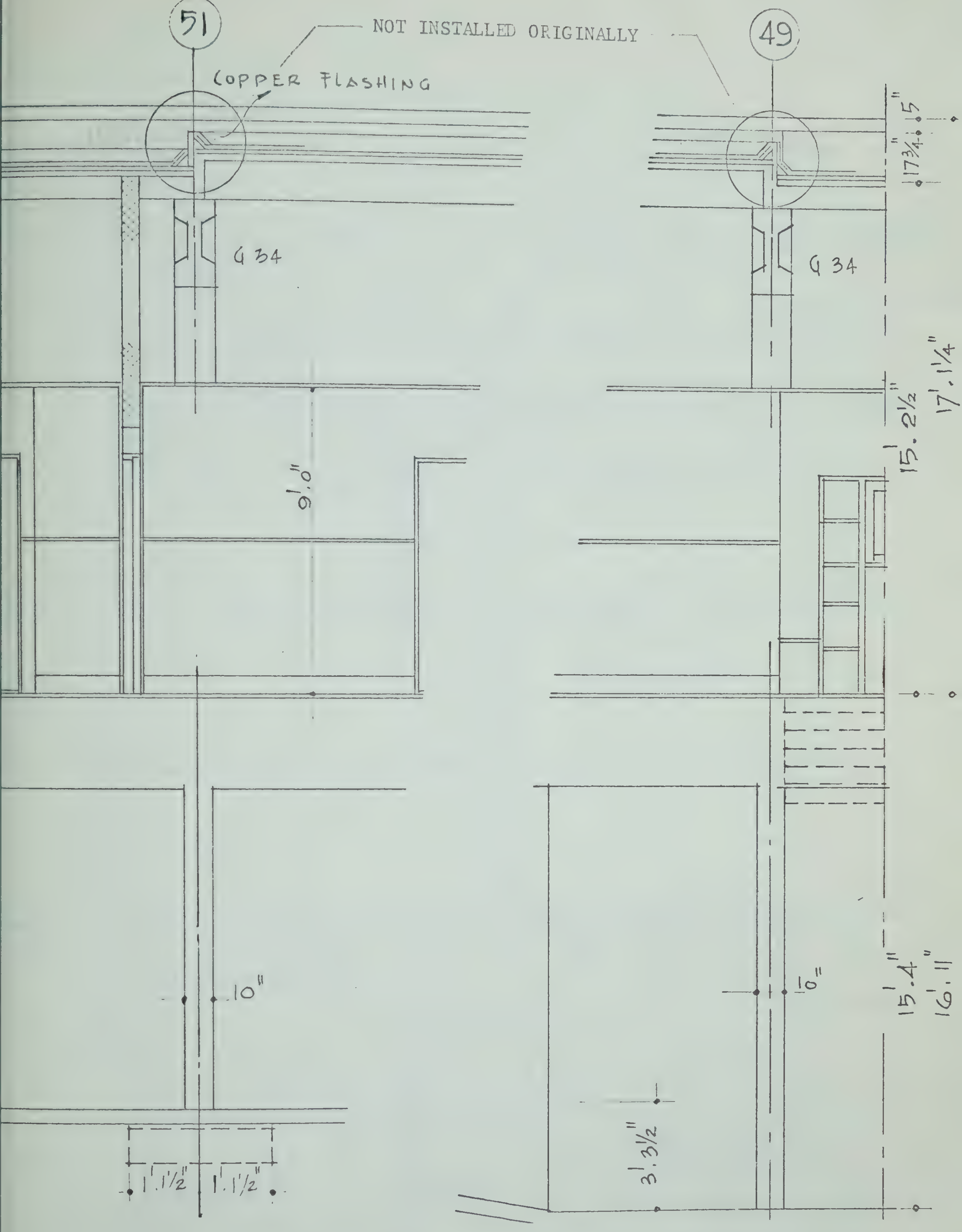
The 1000 squares of roofing on the School for the Deaf represents a rather large investment. When considering an approximate cost of $100 per square to replace the roofing, including flashings, design "economies" such as the exclusion of a vapour barrier, the exclusion of control joints and the minimizing of the flood coat evidently did not pay dividends.

HIGH ROOFS
------ STRUCTURAL CONTROL JOINTS (EXCEPT ROO



KEY PLAN
SCALE 1" = 200'0"
SCHOOL FOR THE DEAF
703/54

FIG. II



SCHOOL FOR THE DEAF, EDMONTON
PLAN 703/54 SHEET #47

FIGURE 12

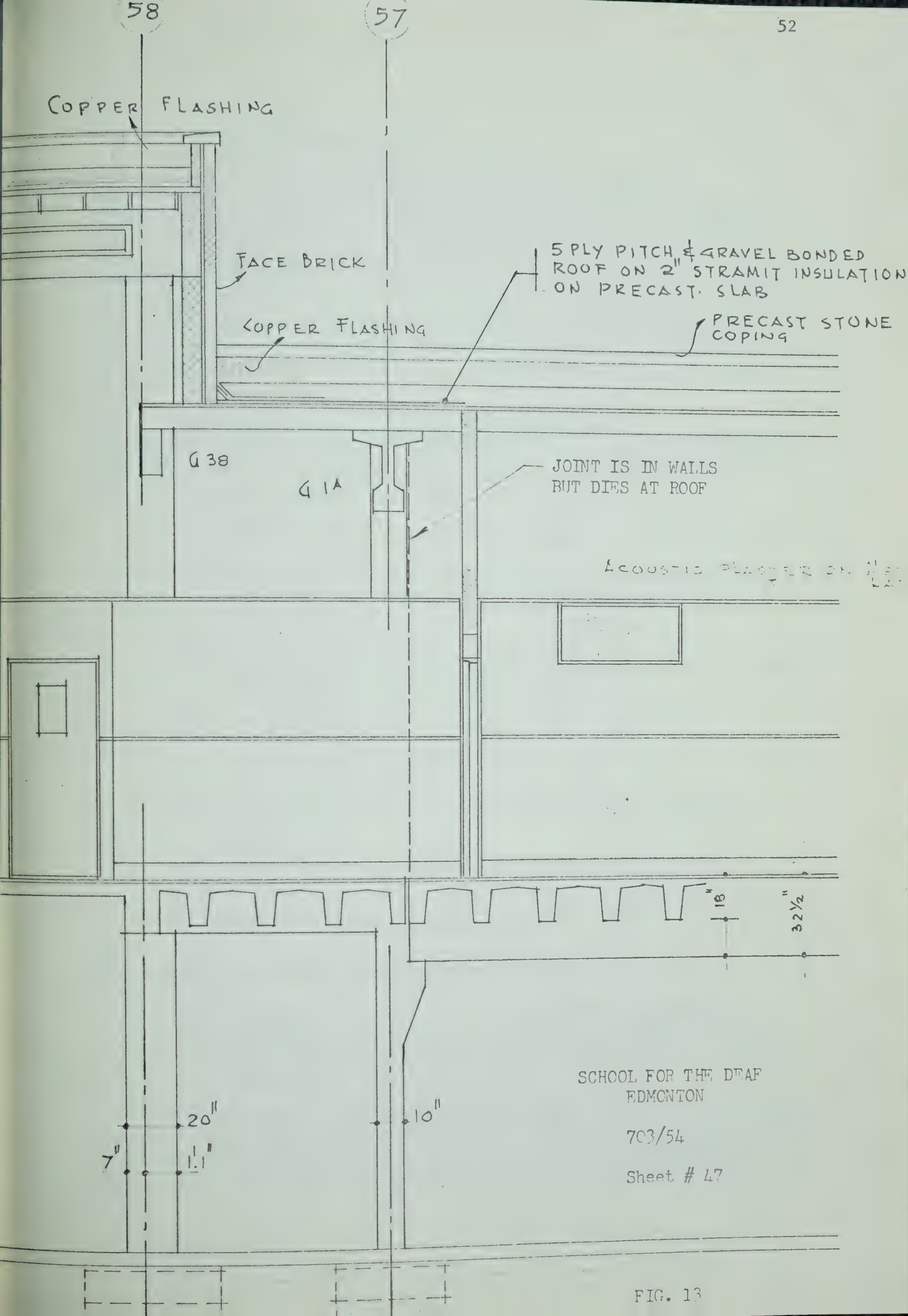

58
57
COPPER FLASHING
FACE BRICK
5 PLY PITCH & GRAVEL BONDED ROOF ON 2" STRAMIT INSULATION ON PRECAST SLAB
COPPER FLASHING
PRECAST STONE COPING
G 38
G 1A
JOINT IS IN WALLS BUT DIES AT ROOF
ACOUSTIC
18"
32½"
20"
10"
7"
1.1"
SCHOOL FOR THE DEAF
EDMONTON
703/54
Sheet # 47

FIG. 13

(b) Terrace Building, Edmonton

This building is of cast-in-place concrete construction. All exterior walls are exposed architectural concrete having polystyrene insulation applied directly to the interior surfaces. The roof is, as are the floors, constructed of cast-in-place concrete joists. The structure consists of five basic blocks, A,B,C,D and E, there being control joints completely separating each of these blocks from the one adjoining. The concrete deck is overlayed by a vapour barrier (rag felt and asphalt), which is in turn overlayed by 2" of Stramit insulation. The insulation is overlayed by a rag felt and asphalt membrane, protected by an asphalt pour coat and gravel. Flashings are of copper. The roof is "dead flat".

The roof of the Terrace Building has been failing almost since its completion in 1960. Water, or water vapour, by one means or another, has penetrated into the insulation, causing it to both lose its insulating value and to rot. (Photos #121 and 122).

On examination of the roof, the following situations were found:

(a) water was ponding at many locations over the roof, as a result of the drains being located at the high spots. (Photo #115)

(b) the roof membrane was slightly buckled in some areas along the joints of the insulation. (Photo #115)

(c) the flashings were poorly installed. (Photo #117)

(d) the flashings were improperly designed.

(e) The Stramit was not caulked or taped at the joints. (Photo #114)

(f) no air cutoffs were installed in the control joints.

(g) no membrane was installed beneath the parapet and control joint cap flashings. (Fig #15)

The reasons for the insulation becoming wet were:

(a) leakage of air through the control joints, under the flashings. (Photos #119 and #120) Moisture from the warm moist air condensed on the underside of the flashings and migrated into the insulation.

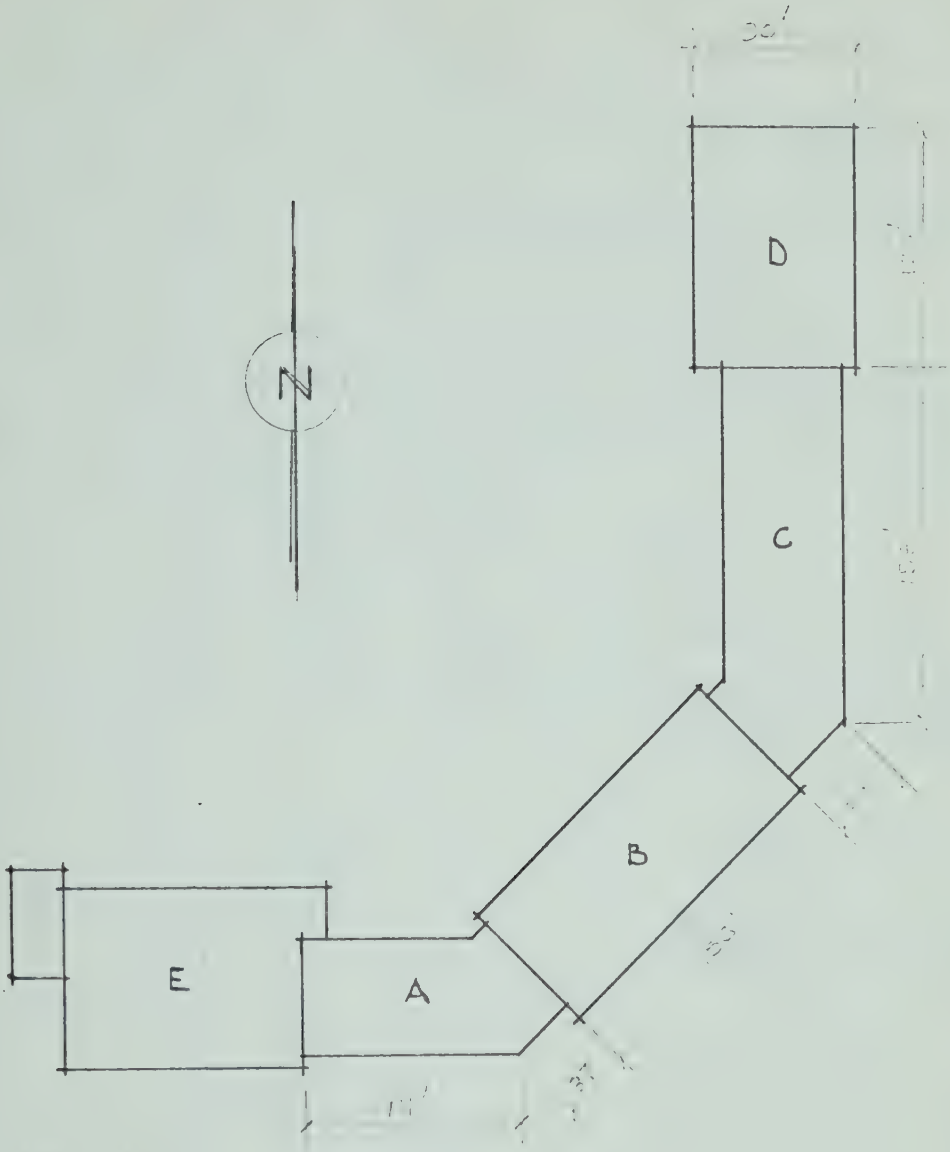
(b) leakage of water through the flashing joints. The flashings are dead flat, the seams are simply short-lapped and caulked on the outside. In some areas, the flashings actually slope to form a water-retaining trough. The joints pulled apart,

allowing melted snow and rain to run into the parapet construction, and thence into the insulation.

It is the writers' opinion that there would have been water dripping through the ceilings of the Terrace Building and the roof repairs would have been just as extensive, regardless of the type of insulation originally installed.

Some of the original flashing defects have been corrected by D.P.W. crews, however, nothing less than complete replacement will in the writers' opinion arrest continuing flashing leakage.

At a cost of \$100 per square to replace roofing and flashing, the cost of replacing even one half of the 500 squares of roofing on the Terrace Building cannot be dismissed lightly as a standard item of maintenance.

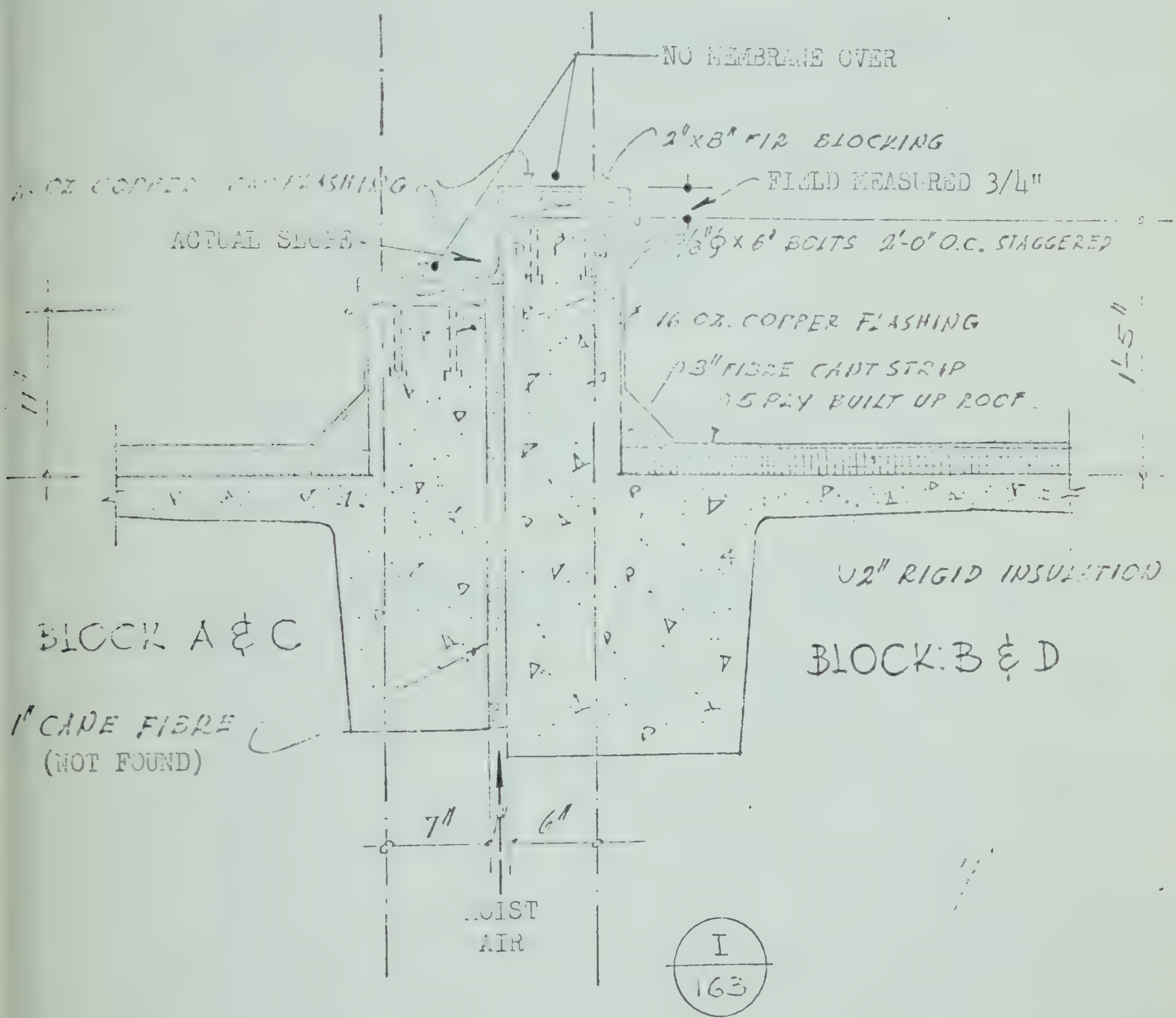


KEY PLAN
Scale 1" = 100'-0"

TERRACE BUILDING, EDMONTON

1307/60

FIGURE 14



TYPICAL EXPANSION JOINT DETAIL AT ROOF LEVEL BETWEEN BLOCK A-B; B-C & C-D

TERRACE BUILDING, EDMONTON
1307/60
SHEET #163

FIGURE 15

(c) Homes for the Aged

The Homes for the Aged are residential units of two basic sizes- the large "U" shaped lodges and the smaller "H" and "T" shaped units. The first of a total of about 140 of the Homes for the Aged units, constructed on about 70 sites, were built in 1959 at Berwyn, Ponoka, Westlock, Drumheller, Bow Island and Innisfail. These buildings are of frame construction, both the cottages and the lodges having very low-pitched roofs. The walls and ceilings are plastered.

Roof problems have been experienced on the following Homes for the Aged sites: (There may be others, but the writers are not aware of them).

McQueen	- Edmonton
Sherwood Park	- Edmonton
Jacques	- Calgary
Bow Valley	- Calgary
Vegreville	

The mode of failure of the roofs of each of the projects noted has been the same; the Stramit roof deck, for one reason or another, became wet, and having lost its strength and rigidity sagged severely between the roof joists.

Up until 1965, the design of the roof system of the buildings remained essentially unchanged. The ceilings consisted of wood joists, vapour barrier, gyproc lath and plaster. The structural roof consisted of wood rafters at 2 feet O.C., and nailed-in-place 2 inch Stramit Structural Roof Deck. The roof membranes consisted of glass or rag felts, Type II asphalt pour coat and gravel. The attic spaces and boxed-in eaves were not vented (Figure #16). In principle, this design could have worked, and for it to work, it was essential that the attic space remain at low wintertime humidity. Possibly too much reliance was put on this one assumption made in the design. In order for the Stramit roof deck to remain dry there could be tolerated almost no escape into the attic of warm moist air from the space below the ceiling. (Reference #12). In practice, this condition was not achieved. Workmanship was generally not good enough, and air leaked into the attics through plaster cracks and around light fixtures and air vents, and no doubt up through the walls. Condensation of moisture in the attic air resulted in the deterioration of both the Stramit deck and the eave soffits. Any instance of interior plastering during the winter would have accelerated the wetting of the Stramit. Such a condition was reported as having existed at the Vegreville site.

Not all problems with the Homes for the Aged arose from conditions within the buildings. Many of the roof membranes have exhibited splits, allowing water to penetrate into the roof deck and building interiors (Photo #124 & #125). Similarily, gravel stops were found sticking up through the membrane (Photo #126). In all reported cases of splits in the membranes, the condition existed (as far as the writer could determine) in membranes composed of glass felts, and the splits were always found

parallel to the machine (long) direction of the felts.

In 1965, the roof structure and ceiling design was revised, the first of the units incorporating the new design having been constructed at the Ottewell, Belvedere and Rosslyn sites in Edmonton, and sites in Grande Prairie, Bashaw and Sylvan Lake. This revised design is now basically the same as that used for the majority of frame houses constructed on the prairies. The spaces between the ceiling joists are insulated with 3 inch glass fiber batt and the rafters over the attic space are sheathed with wood shiplap. The roof membrane is applied directly to the dry paper covered wood sheathing. The attic spaces and boxed eaves are vented. (Figure #17). The difference between the two designs is basically; the old had a warm vented attic and the new has a cold vented attic. The old had the membrane bonded directly to the insulation, and the new has a large air space between membrane and insulation.

What conclusions are now to be drawn? The following is a list of cases and facts which the writers' have considered:

1. Only a minor percentage of the Homes for the Aged have been reported as having experienced roof failures. Why have they not all failed?

2. Upon reroofing of some Calgary units, it was reported that the ceiling vapour barrier called for was not installed.

3. Upon reroofing of some units, it was reported that the insulation between attic and eave space was not installed and some Stramit edges were not bearing on the joists.

4. McQueen site units were reported as having bathroom vent pipes not connected to roof openings, resulting in very moist air being forced directly into the attic space.

5. One McQueen site unit has a ripped membrane resulting from improperly installed gravel stops. It is expected this same situation would be found as existing on many other units if they were to be inspected.

6. McQueen site units now have room exhausts connected to roof vents, however, the pipes stop short of the top of the Stramit. It appears that moist air is being forced into the untaped cut edges of the Stramit.

7. McQueen site units are suffering from moist air gaining access to the boxed eaves. The paint is peeling from the eave soffits.

8. Many Homes for the Aged roofed with glass felts have split membranes.

9. The Government has many buildings roofed with Stramit Structural deck, other than Homes for the Aged, which are performing satisfactorily.

10. Many schools and apartment buildings throughout the province have been constructed using a flat roof structure of wood joists, overlayed by Stramit Structural Roof Deck, with vapour barrier and plaster ceiling applied directly to the underside of the joists to form the ceiling. The air space between the joists in this construction is unvented. Little trouble has been reported by the owners of these schools and apartments.

11. Many residential homes in the province are roofed in the same way as were the Homes for the Aged. Homes roofed in 1958 are still performing saitsfactorily.

12. Up until 1960 Stramit had no water-proof covering, however, since 1960 Stramit has been available with a polythene sheet bonded to one face. (At present, it is also available having a tough vinyl covering on one face and all edges). Would a change to this type of material have helped any?

It has been suggested to the writers that frost accumulated on the metal Tee bars during cold weather and upon melting in the spring the water formed then soaked into the Stramit. It has been further suggested that moisture migrated through the uncaulked joints between Stramit sheets and condensed on the underside of the cold roofing membrane, thus wetting the Stramit. Both of these situations could have existed, however, no actual cases were cited to the writers.

An unvented warm air space beneath Stramit Structural Roof Deck appears to cause no major problems unless the humidity within the building is high, and the vapour barrier incorporated into the ceiling and wall construction is ineffective. When humidification of a building rises above the level common to average residential buildings, a condition might be created which would render the warm unvented attic or ceiling space type of construction critical. The higher the interior relative humidity, the more critical the design and workmanship will likely become.

The Homes for the Aged are no more highly humidified than are most Alberta houses, making it difficult to determine, without actual field measurements, why some of the Stramit Structural Roof Deck construction failed, but most of it did not. The conclusion left to be drawn is that workmanship most probably was poor in those buildings which experienced roof failures, and more attention to details of design might well have prevented some of the failures that did occur. The reversion of the "old style" roof system seems to be an admission by the Department of Public Works that it is not worthwhile to strengthen the weak points in the design and that workmanship provided to the Government by some building contractors is not of a high enough standard.

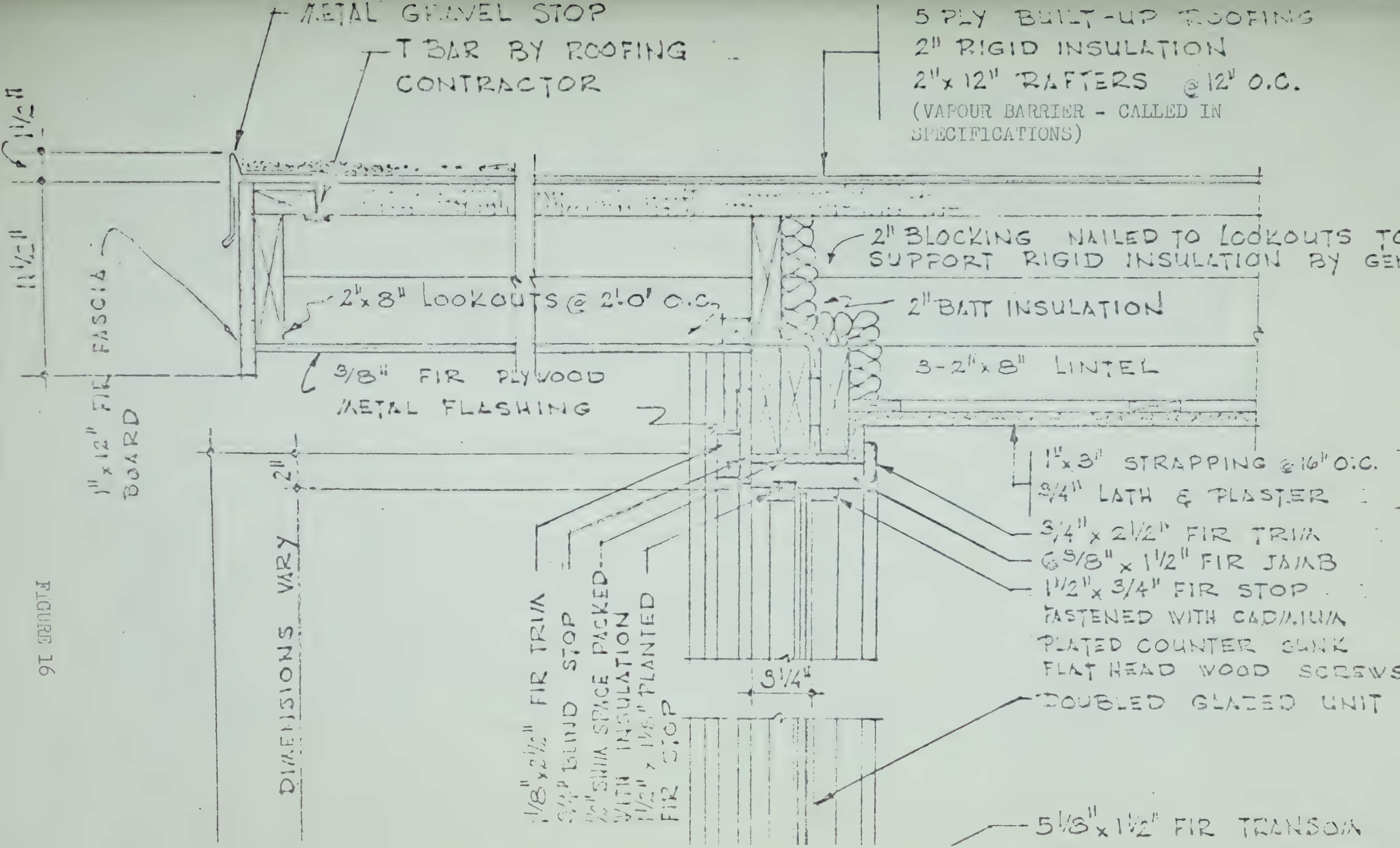
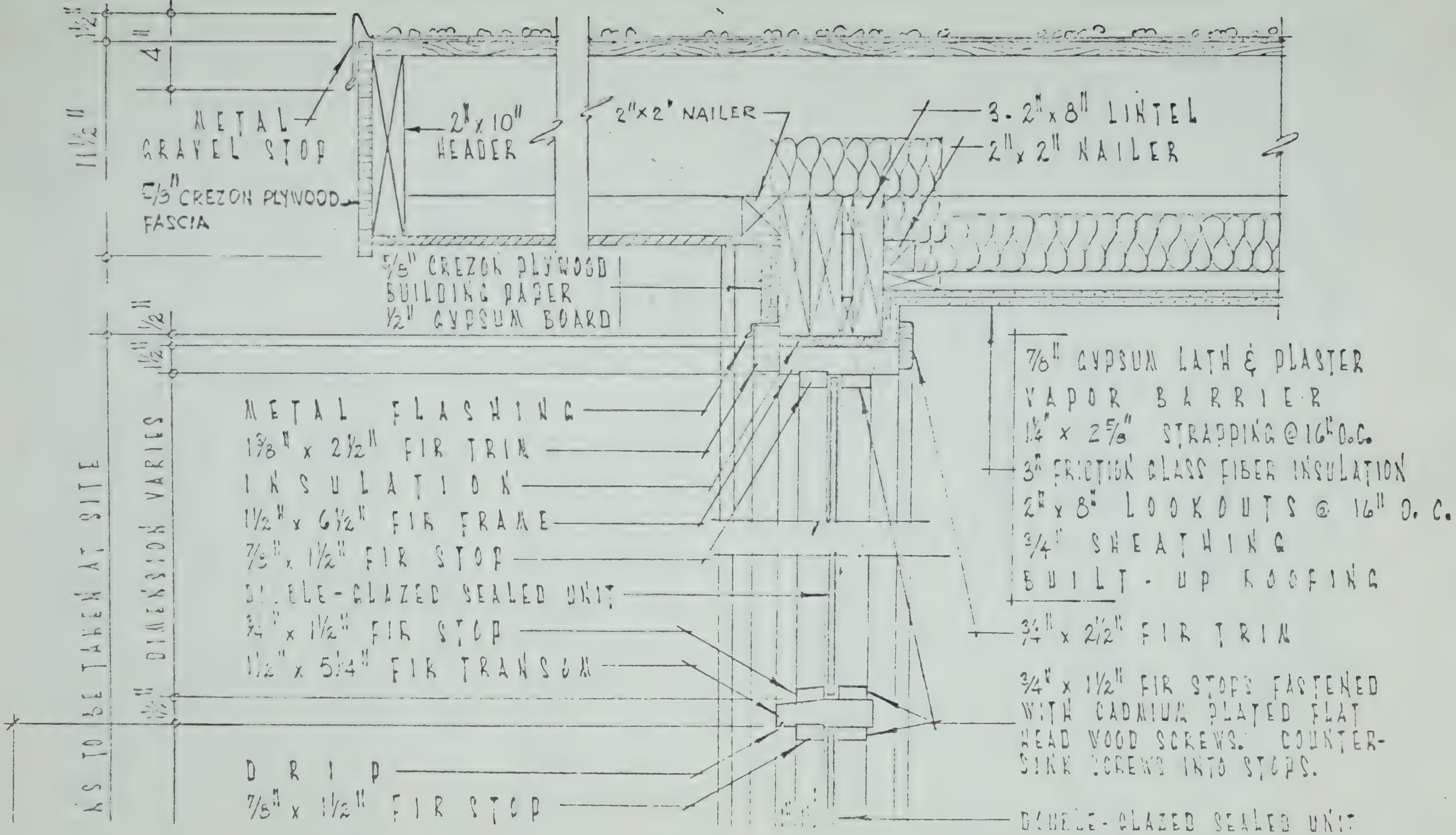


FIGURE 16

HOME FOR THE AGED

ORIGINAL DESIGN



HOME FOR THE AGED

REVISED DESIGN, 1965

FIGURE 17

(d) The Northern Alberta Institute of Technology

The N. A. I. T., phases I, II and III was completed in the summer of 1963. The structures of phases I and II are framed of precast concrete. The structure of phase III is framed of cast-in-place concrete. All structural roof systems are either precast or cast-in-place concrete joists.

Phase I of this building was roofed using a polystyrene bead board (paper covered top face) and glass fiber roofing felts. Phase III was roofed using wood fiberboard and glass felts. All flashings originally were of copper.

Since its completion, roof leaks at N. A. I. T., have been a continuing problem. Roofing and flashing repairs of major proportions are being carried out regularly.

The major problems with the roofing of the Technical School have resulted from faulty design of the flashings, faulty design of the roofing control joints, insufficient asphalt on the built-up roof pour coat and excessive movement of the structural frame. Any one or combination of these faults could have been the reason for roof leaks.

Upon examination of the roof of the Technical School, the following things were noted:

1. The original flashings, still existing, are of copper. Much of this material is badly corroded and unsightly.

2. The flashings of the Technical Block of Phase III were designed to be flat on top, however they were installed generally with slight slopes toward their longitudinal centerlines. Water was seen standing on these flashings. (Photos #142 & #143).

3. Flashing joints are generally caulked and almost all joint caulking is cracked (Photos # 143 and #147).

4. Very few of the originally installed roof drains were seen to be functioning as they were intended to function. Many pools of water, both large and small, were seen standing on the roof.

5. Newly installed roof drains are prevalent on Phase III areas.

6. The roof membrane of Phase III exhibits many patches necessitated by the widespread splitting of the membrane. (Photos #144 and #146.)

7. At a 5" change in roof elevation toward the east end of the Technical Block of phase III, deep fissures in the asphalt pour coat are numerous (Photos #144 & #146). No metal gravel stop exists at this change of roof elevation.

8. Drip legs of original flashings are only $1\frac{1}{2}$" or less in most details - far too short. (Photos #142 & #143).

9. Wooden sleepers for wooden walks are layed directly onto the roof membrane surface.

10. Original flashings still in place have "S" bend joints only 1" long and less in places.

11. Base flashings in many areas are pulled loose from the brick work due to improper design being able to accomodate normal dimensional changes of building materials. (Photos #152 & #153)

12. Many of the soldered joints in the original copper flashings are torn apart. (Photo #147).

13. Much of the original copper flashing has been removed, and new painted galvanized iron flashings are installed. The original flashings did not function properly.

14. Joints in the precast concrete structure are now all flashed. Excessive movement in the structure rendered the caulking at these joints, as a water barrier, almost useless. (Photos #141 & #150).

15. In many roof areas, there is little or no gravel protecting the pour coat of asphalt.

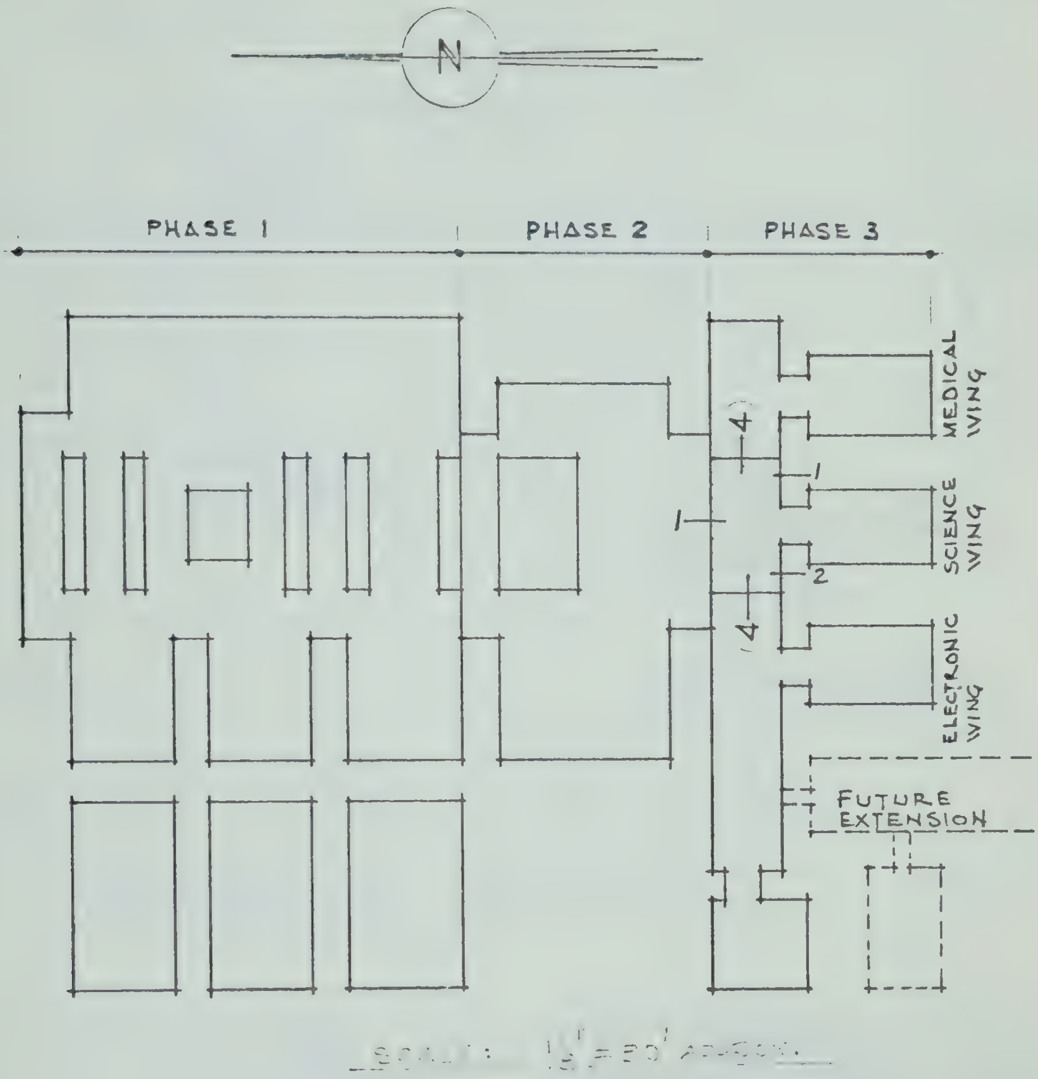
16. The wood fiberboard insulated roof of phase III looks to be in worse condition than does the polystyrene board insulated roof of phase I.

One of the major factors leading to the failure of the roofing of some areas of phase III was the excessive deflection of the structural roof system. Water collected in the deflected areas, and ponded over the roofing control joints. Since the roof membrane is not continuous over the joints, the water passed through the flashing joints and ran into the building.

The N. A. I. T. roof flashings show, as do those of the Terrace Building and the School for the Deaf, that a design concept of watertight flashings is, in the main, impractical. The fundamental concept of a flashing is that it protect the watertight roof membrane, not that it be a replacement for the roof membrane. This last noted concept has been completely disregarded.

The area of the roof of the N. A. I. T. is roughly 4500 squares. The cost to replace the roofing, including flashings, is estimated at \$100 per square. Had the design of the roofs and roofing systems been carried out with more care, it is almost a certainty in the writers' opinion that only a very small proportion of this money would have to be spent to rectify problems arising from faulty materials and workmanship.

It is the writers' opinion that the roof of the Northern Alberta Institute of Technology would have leaked regardless of the type of felts or insulation used.



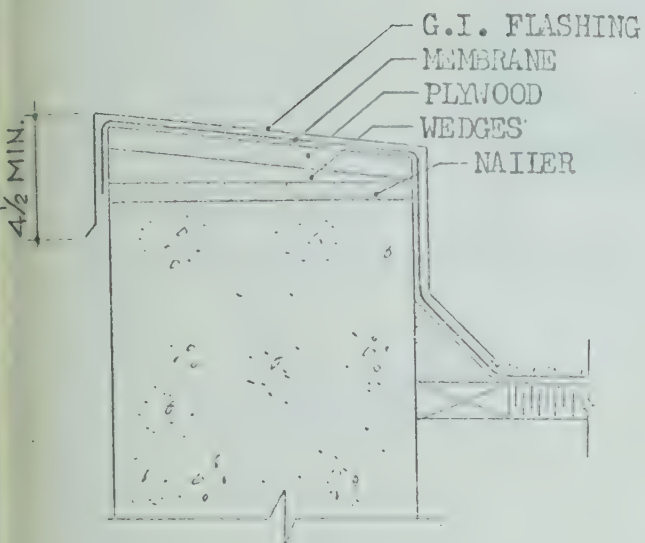
KEY PLAN

NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY - EDMONTON

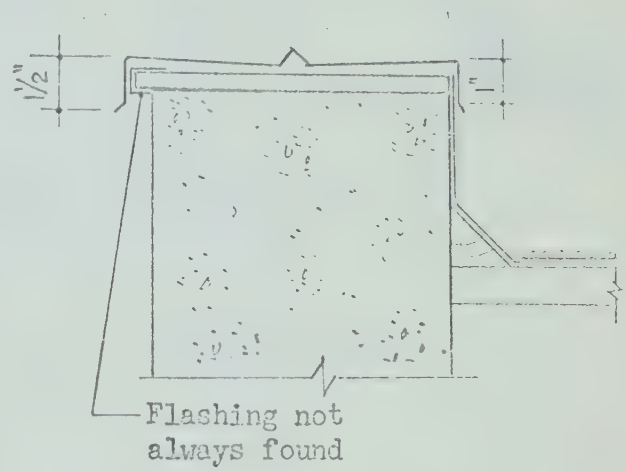
1350 - III

FIG. 18

Page 66: The details should appear as follows:



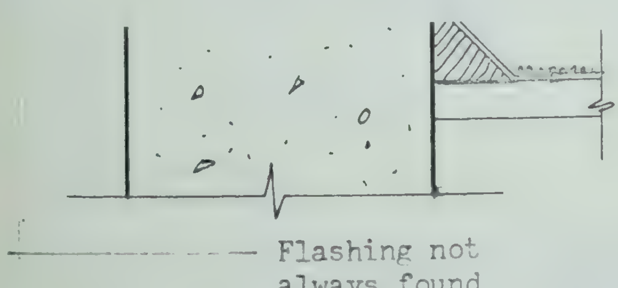
FLASHING REDONE



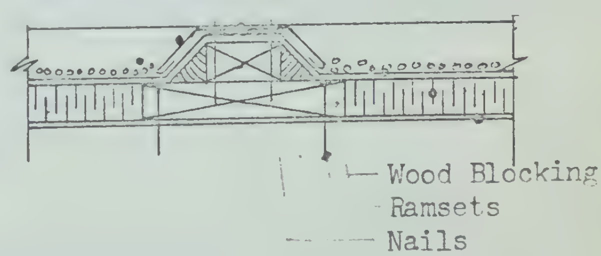
POOR FLASHING DETAIL EXTENSIVELY USED

Photo #128: A title at the head of this page should read:

SCHOOL FOR THE DEAF - PHOTOS 128 to 138



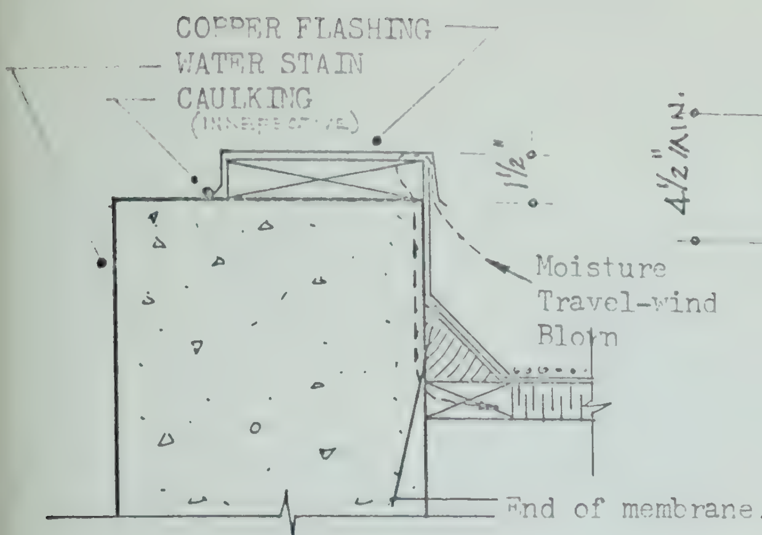
POOR FLASHING DETAIL EXTENSIVELY USED



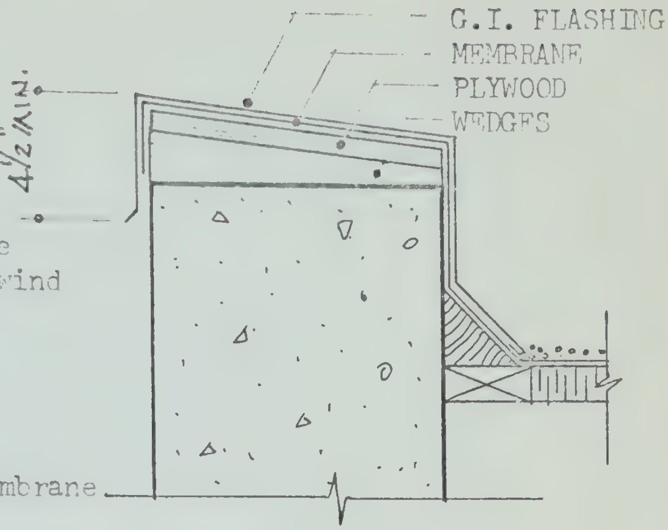
WALKWAY SUPPORT DETAIL INCORPORATED INTO REROOFING OF MEDICAL WING-ORIGINAL DETAIL HAD 2 x 4 SLEEPERS SET DIRECTLY ON GRAVEL

N.A.I.T. FLASHING DETAILS

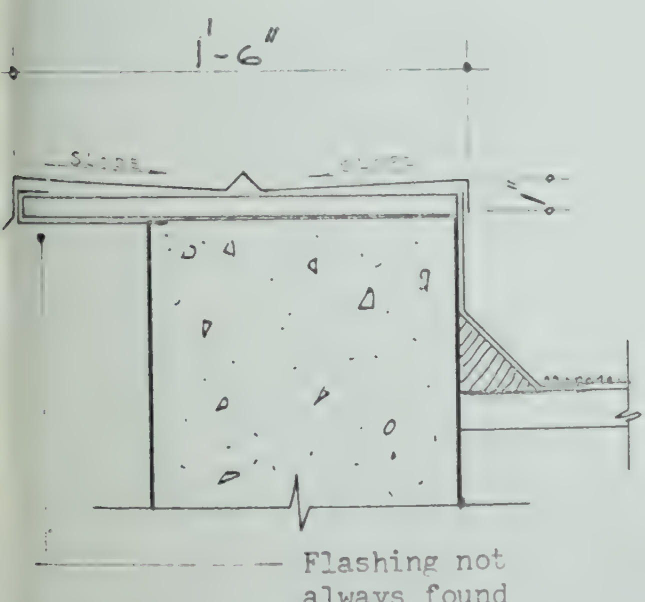
FIG. 19



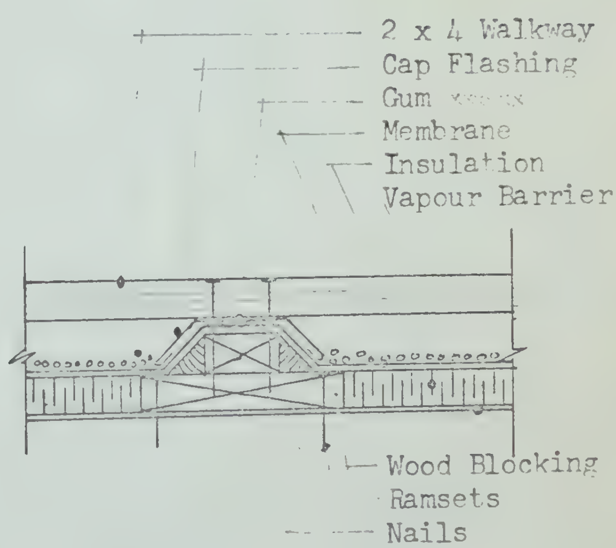
ORIGINAL FLASHING
TO P.C. CONCRETE BEAM



FLASHING REDONE



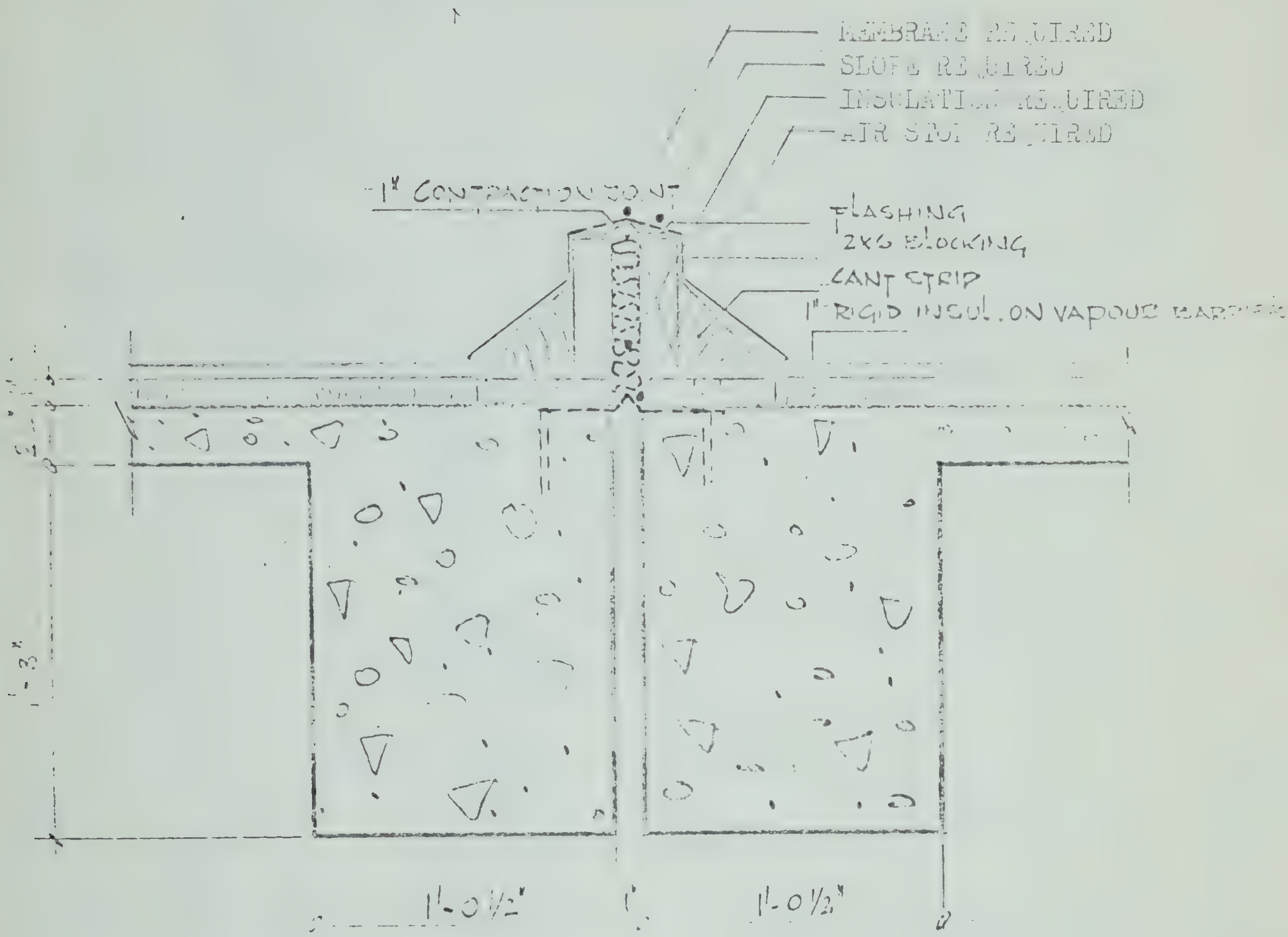
POOR FLASHING DETAIL
EXTENSIVELY USED



WALKWAY SUPPORT DETAIL
INCORPORATED INTO REROOFING
OF MEDICAL WING-ORIGINAL
DETAIL HAD 2 x 4 SLEEPERS
SET DIRECTLY ON GRAVEL

N.A.I.T. FLASHING DETAILS

FIG. 19



DETAIL 4/11

NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY
1350/60
PHASE III
SHEET #11

FIGURE 20

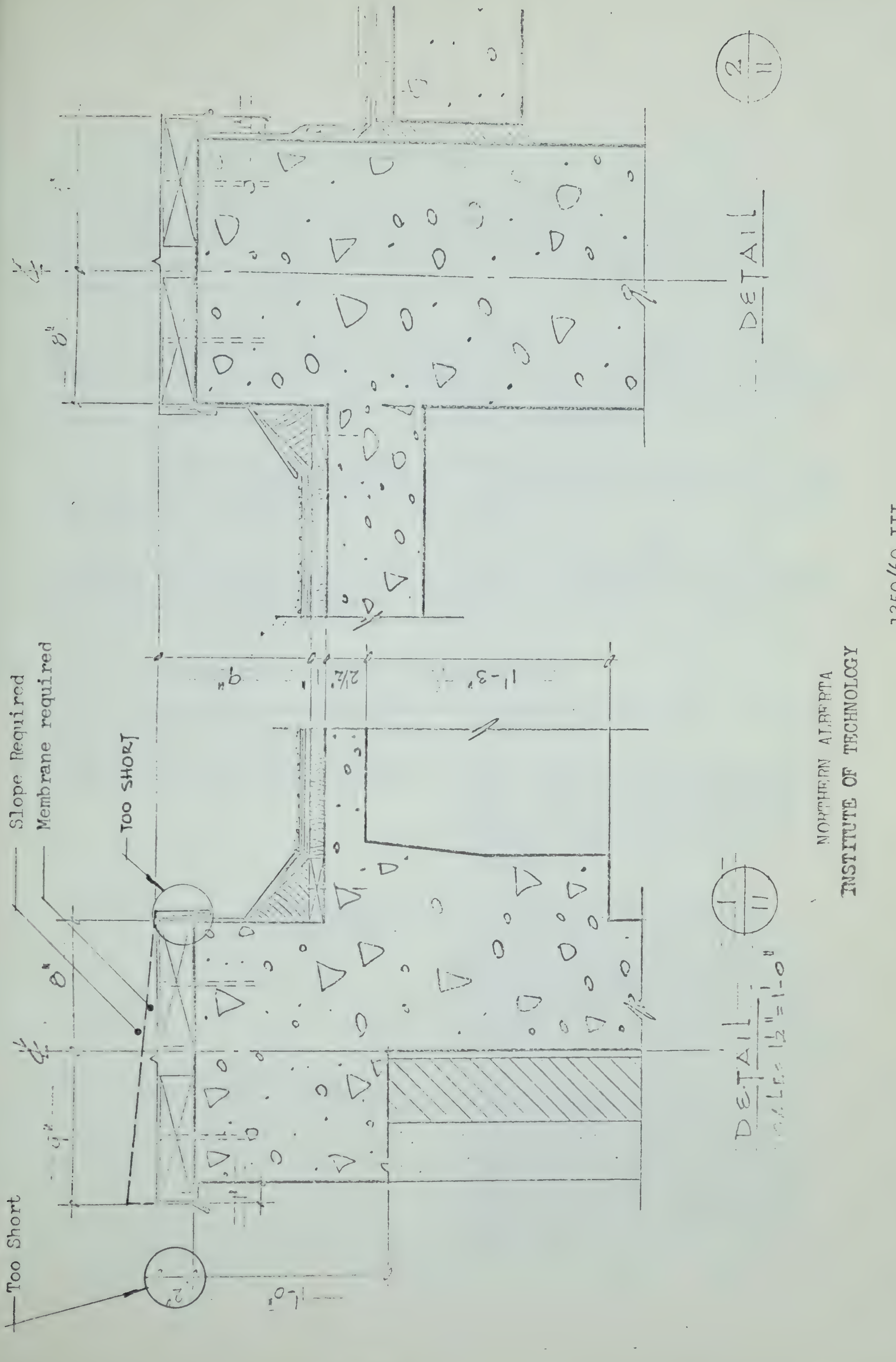

Slope Required
Membrane required
TOO SHORT
Too Short
DETAIL
DETAIL
SCALE: 1½" = 1'-0"
NORTHERN ALBERTA
INSTITUTE OF TECHNOLOGY
1350/60 III
Sheet # 11

FIG. 21

(e) Other Buildings Involving Stramit

The University of Alberta Interns' Residence is a cast-in-place concrete building, and was roofed using Stramit insulation. The roof leaked and investigation showed that chairs had been taken by the occupants onto the roof. The chair legs punctured the membrane, and the Stramit subsequently became wet.

The Plant Science Building, Olds Agricultural and Vocational College, incorporated Stramit insulation over a precast concrete roof deck. The flashings on this building, for reasons unknown, were repeatedly being blown loose by the wind. The Stramit subsequently became wet due to water penetrating through the ineffective flashing.

The University of Calgary Science and Engineering Building is of cast-in-place concrete. Buckling of the membrane was reported some years ago. The roof membrane did not leak, however.

The Occupational Therapy Building at Deerhome experienced a complete roofing failure about five years after completion. For reasons unknown, the Stramit insulation became wet, rotted, and consequently the insulation and membrane had to be replaced.

(f) Other Roofing Failures - Brief Outline

The following information was reported to the writers. None of the projects listed were inspected by the writers.

Federal Public Building, Edmonton	Wood fiberboard over gypsum deck--sudden heavy rain washed gravel against drains, and plugged the screens. Water leaked under flashings.
A.G.T. Building (now Agriculture) Edmonton	2" Fiberglass insulation over concrete slab. Roof on 6 yrs. with no trouble. Roof membrane accidentally punctured near Penthouse, and 2" of water filled the insulation completely. Built-up roof had to be replaced completely.
Continental Can Co., Edmonton	Metal deck over steel joists. Stramit insulation, glass fabric roof membrane. Butt joints opened up, and bitumen drained out of membrane, leaving dry felt strips along joints. Water penetrated through joints and insulation became wet.

#7 Supply Depot, Edmonton	17 acres of roof - rigid Fiberglass-no control joints in roofing - membrane was run continuously over pseudo joints-membrane "wore out" at cant strips due to continual lifting and flexing with temperature changes.
Henry Marshall Tory, University of Alberta, Edmonton	Entire east wing (adjacent to tower) had to be reroofed due to mechanical damage to first layed roofing.
Museum & Archives, Edmonton	250 squares (North Wing) replaced because of mechanical damage to first layed roofing - approximate cost $20,000.
Students Union, University of Alberta, Edmonton	Mechanical damage to low roof areas-about 60 squares had to be repaired-approximate cost $5000.
Services Building, Alberta Hospital, Red Deer	Asphalt delivered in poor containers and literally dumped at site - cardboard mixed with asphalt. Plastic foam on metal deck. Foam melted upon application of too hot asphalt. Much of roof was replaced by contractor, using fiberboard.
Medical Arts Building, Edmonton	Zonolite insulating concrete fill over metal deck - Nailers set into Zonolite. Some nails used to affix insulation to nailers missed the nailers, and in time gradually worked up through membrane, causing leaks.
St. Frances School, Calgary	300 squares with no control joints in built-up roofing - roof membrane split, was reroofed with no control joints, and split again. Last roofing had control joints, and no problems reported as having since developed.
Northgate, Edmonton	Dec. 1964. Concrete deck, some areas metal deck. 2 ply V.B., 2" fiberboard 3 ply glass fiber membrane, positive drainage, and joints in membrane at 100' max. each way - flashing good. Roof membrane split in over 80 places, and had to be replaced. Splits about 20' apart. Most troubles occurred in concrete deck area. All areas repaired done

	with rag felt. No problems with repaired areas, but remaining glass areas continue to split.
2 dorms, Alberta Hosp. Claresholm	2" Stramit - membrane buckled along joint lines in insulation.
River Glen School, Red Deer	Stramit over precast - water permeable parapet (or similar wall) conducted water directly into insulation.
F.P.G.H. Power Plant, Calgary	Precast deck & Zonolite concrete topping. Glass fiber membrane roofing. Membrane split, and roof leaked.
Angus Building, Edmonton	Wood deck, fiberboard insulation, glass fabric membrane - roof leaked.
Jasper School	Foamed plastic insulation and glass membrane. Membrane split.
Wildwood School	Foamed plastic insulation - Roof leaked.
Cambrian Building, Edmonton	Concrete deck, Stramit, 2 ply glass fabric membrane - roof leaked.
Wetaskiwin Clinic	Glass fabric membrane over 2" fiberboard over metal deck-membrane split, and repairs continue to split.

(g) SOME FAIL - MOST DON'T

In virtually every discussion held with roofers and manufacturers of roofing materials, for every example of a roof failure described, examples of successes were described which contradicted the theories put forth on the failure. The following are some examples:

1. "Glass felts split too often".

   The glass felt manufacturers do not deny that their felts have split on many roofs, but point out there are many thousands of glass felt roofs in this northern climate which have not split and are performing satisfactorily.

2. "Roofing control joints must be used".

   Some roofs failed through lack of joints, as apparently proved by satisfactory performance of the same roofs after relaying with joints. Other roofs, acres in size, have no joints and have performed saitsfactorily for years.

3. "Stramit roofs are no good".

   Many roofs, in fact, in which Stramit was used have failed for one reason or another, but there are hundreds which are performing excellently, whether on wood joists, metal deck or concrete deck. Dominion stores has a roof area of 16,000 feet (Stramit over metal deck, no joints in roofing), and is performing without troubles. Our own multi-stall garages have not in any instance been reported as having given trouble. Wood fiberboard deteriorates just as does Stramit if it gets wet.

4. "Wood fiberboard insulated roofs are trouble-free".

   Northgate Shopping Center used wood fiberboard and it failed. The fiberboard got wet and the roof had to be replaced. This roof, according to persons in the trade, was designed as well as a roof could be and yet it failed. The Museum and Archives building used wood fiberboard and 250 squares had to be replaced.

5. "Roofmate is a bad risk - it's coefficient of expansion is too great, and hot asphalt melts it".

   There have been failures of roofs insulated with Roofmate, however, there are many hundreds of roofs which have been insulated with Roofmate which have performed satisfactorily. This is an excellent insulation, however, when applied to roofs, care must be exercised in the design of the roofing system.

6. "Zonolite concrete causes roof membranes to blister".

   Quite true in some cases, but again many roof membranes over materials other than Zonolite blister also. Hundreds of roof membranes placed over Zonolite concrete are performing satisfactorily.

Every common roofing material used today could undoubtedly be found in a roof which has failed and for every five instances of failure, there are probably ninety-five instances of success. In fact, the most commonly quoted figure on roofing failures is 5% or less.

Attempts have been made to compare roofs of "identical" construction in an effort to show why one failed and the other performed saitsfactorily. The word "identical" is in quotes because in fact, no two roofs could be identical. The materials of construction - the deck, the asphalt, the insulation and the felts- in all probability vary, even if only slightly, in physical and chemical properties. The climatic conditions during application (temperature, humidity, wind, frost, sunshine) could in all probability not be identical. Combinations of many conditions, perhaps insignificant when considered singly, might

well result in a total condition detrimental to the construction of a good roof. When considering variables such as workmanship, quality of materials, climatic conditions (both inside and outside the building), physical properties of particular materials and interaction of materials having widely differing physical properties in intimate contact with each other, it is not surprising that no one yet has been able to set forth a specification for a roof which is "fail proof", or that researchers have not come up with a cure-all answer as to why roofs fail.

In many instances of failure it is the opinion of the writers that the failure was due principally to faulty design or faulty workmanship, or a combination of these two things, and was not due to the materials of construction.

As a post-script to this section of the report dealing with specific failures and the probable reasons for them, the writers feel the following paragraph might be noted as having a bearing on poor performance of some built-up roofs.

The Department of Public Works has met with difficulty in the past when departmental approvals were not granted for the use of materials which, for valid reasons, the designers felt were not compatable with other materials used in their design. It is interesting to note that several of the material suppliers interviewed stated that if certain other products were to be used in a built-up roof, they would not quote on the work, even though their product was specified. There were very definite views expressed to the writers by some companies as to what materials of construction they felt they were willing to have used in conjunction with their own. In some cases, their product was allowed to be used, but only if the manufacturer of the other product would post a guarantee of some sort, to cover mis-performance or failure of the built-up roof.

VII BONDS & GUARANTEES

Prior to 1961, the insurance against failure of a completed roof membrane was guaranteed by bond. A roof bond, usually in force for 15 or 20 years, was delivered to the owner, at the owner's request and expense, by the manufacturers of the roofing materials. The cost of a 20 year bond was about $0.25 per square. The bond was generally only of value if the roof actually leaked. Bonding of roofs was discontinued in Canada late in 1961, the major reason beings its ineffectiveness. There were simply too many conditions which could render the bond void.

Presently the Canadian Roofing Contractors Association (C.R.C.A.) utilizes a Certificate of Guarantee. This guarantee covers the roof membrane and membrane flashings for two years, and can be successfully invoked only when a failure can be shown to have resulted from faulty workmanship or ordinary wear and tear by the elements. The guarantee is as effective as are the guarantees given by the materials manufacturers, with respect to those materials. In effect, this guarantee is much the same as was the bond.

One only has to read the conditions of the guarantee to realize that basically the same problems still exist as existed with the bond. The determination of why a roof membrane failed is generally a complex problem. It is more often a matter of opinion than fact, and the onus of proof would still appear to rest with the owner.

The A.R.C.A. guarantee offers some protection to the owner, however, it is no substitute for good design, materials and workmanship.

VIII SPECIFICATIONS

(a) Alberta Roofing Contractors Association Ltd.

The A.R.C.A. has been active in Alberta for about the last ten years. The association was incorporated approximately three years ago. As of January 1966, it has an active membership of thirty-one Alberta roofing contractors, and an associate membership of fourteen manufacturers and suppliers.

The A.R.C.A. has adopted the Canadian Roofing Contractors Association Limited (C.R.C.A.) roofing specification manual as its basic specification. Amendments are issued from time to time to keep the specification current.

The writers have reviewed the C.R.C.A. specifications, and are in general agreement with the majority of the material presented. A few of the points of disagreement are:

1. Acceptance of the use of 8# glass felts (6.0,7.4, etc.).
2. Acceptance of the use of permanent interior water cutoffs (5.0).
3. Absence of requirement for mechanical circulation device in asphalt tanks (5.0.1).
4. Absence of requirement for the covering of nail heads with insulation (5.0.2).
5. Optional requirement regarding two on two felt application (5.0.3).
6. Possible impractical requirement regarding wrinkles or buckles (5.0.4).
7. Absence of requirement for reinforcing patches over cut tests (5.0.4).
8. Absence of any reference to stapling of insulation, in lieu of nailing (7.0).
9. Directive to use Type I asphalt on roofs with slopes 0" to 1" per foot.
10. Directives to use too little quantities of asphalt between roofing felt plies and on flood coat.
11. Absence of alternative use of base sheet V.B. (11.1).

The reasons for these disagreements have been covered in the text of this report.

For the use of the Department of Public Works, the following specific roofing specifications, as contained in the C.R.C.A. manual

are recommended (with such modifications as noted above having been made).

Sec. 7.0- Wood & Gypsum Decks-not insulated;W1,W3,W5,W6

Sec. 8.0- Wood & Gypsum Decks-insulated; W1-1,W1-3,W1-5,W1-6

Sec. 9.0- Concrete Deck-not insulated; C1,C3,C5,C6

Sec.10.0- Concrete Deck-insulated; C1-1,C1-3,C1-5,C1-6

Sec.11.0- Steel Deck-insulated; S1-1,S1-3,S1-5,S1-6

The last digit of each designation indicates type of material. Digits 3 and 6 indicate selvage edge roofing and possibly should be deleted because of the little use made by the Government of this type of roofing.

The majority of roofing contractors in the Province are familiar with C.R.C.A. specifications, and the use of the C.R.C.A. specification manual as a basic standard would certainly appear to be expedient.

(b) Department of Public Works Standard Specification-Moisture Protection Division Seven, Roofing and Sheet Metal Section.

This specification has been in use by the Department for about one year. After having studied this specification, the writers wish to make the following observations and recommendations, with regard to the items which refer to roofing only (the specification covers other areas of moisture protection besides roofing.

1. Heading #4, regarding storage and handling of materials has basically the same intent as do the majority of roofing specifications. It was noted, however, that even on projects with both D.P.W. inspectors and private roofing inspectors assigned, proper protection and storage of roofing materials were not in evidence, and were not being enforced. Materials which became wet during application were not rejected on any project the writers inspected. It is recommended that this section of the specification be reviewed and revised.

2. Heading #5 regarding materials, makes reference to roofing pitch and tarred felts. Neither of these materials is in general use today. It is suggested that reference to pitch and tar be deleted from the specification. If ever specifically required, the reference can be placed in the particular specification in which it is required.

   Thirteen and fifteen pound glass felts are available to the roofing trade. The writers suspect that the 8# glass felt used in past years could have been a contributing factor in the failure of glass felt membranes. It is recommended that the reference to 8# glass felt be altered to 13# or 15# glass felt. Since saturated cotton is not generally used by roofers in Alberta, reference to this material might be deleted.

Under subheading #2, reference is made to asphalt impregnated wood fiberboard. It is recommended this be changed to "wood fiberboard, one face factory coated with Type III asphalt." It is further recommended that other insulations be listed, along with applicable thicknesses as outlined under Section IX of this report.

Under subheading #3, 15# asphalt felt is called for as a vapour barrier over wood deck. It is recommended that this be revised to a heavy waxed kraft overlaid by two ply of 15# felt. (See Sec. V)

The reliance on a four mil plastic film vapour barrier is questioned, regarding the reference to vapour barriers over steel deck. It is suggested that this film, if it must be used to obtain a certain fire rating, be layed with extreme care, so that it will indeed function as a vapour barrier.

Under subheading 4, it is noted that only 26 guage style of galvanized iron is listed. It is recommended that this be revised to indicate that 26 guage be used for girths up to and including 12" and 24 guage be used for girths over 12".

Under subheading 8, regarding asphalt impregnation, it is suggested the reference to asphalt impregnation be deleted.

Under subheading 9, instances where expansion joints are to be installed are outlined. The 5000 sq. ft. area is somewhat of an arbitrary figure. The shape of the roof is many times more important than is the size of the roof. It is recommended that the locations of control joints in the built-up roof be detailed on the drawings, and a reference to these details be noted under subheading 9. If it is felt this recommendation is not "tight" enough, then the present specification outline of locations of joints should be enlarged.

Under subheading 12, the inference seems to exist that it is acceptable to caulk all flashing joints. This point should be clarified. Joints properly designed and assembled should require no external caulking. There should be a waterproof membrane of some sort under all roof flashings.

3. Heading #9 refers to acceptable surface conditions of "poured concrete decks". It is suggested the word "Poured" be deleted in order that the intent be made more clear. The writers noted that, on several projects, wet or damp surfaces were being roofed over. It is suggested this section be examined further regarding interpretation.

4. Heading #9 requires the installation of built-up roofings to be in accordance with the C.R.C.A. It is recommended this requirement be amended so that it corresponds with those revisions to the C.R.C.A. specifications recommended in VIII(a).

5. Heading #11 deals with flashings. Subheading 5 notes "All corners and seams are to be soldered". It is recommended that only very special joints or seams be soldered and general reference to soldering

be deleted from the specification.

Under subheading 6, the term "flashing lengths" seems to conflict with "at not less than 20 ft. o.c.". The maximum material length from which flashings are fabricated is 10ft., however 8 ft. is most common. Roofing contractors in the main, fabricate an "S" bend expansion joint in each 8 ft. length of flashing, so that points of anchorage do not become too widely spaced. If an expansion joint is to be provided in flashings at distances not less than 20 feet, intermediate anchorages must be designed to permit the flashings to move, otherwise the joints will not function as intended. It is recommended subheading 6 be rewritten.

6. Heading #12 covers Roofing Inspection. Until such times as workmanship within the roofing trade becomes more reliable it is the writers' opinion that the requirements for roofing inspection as outlined are basically ineffective. In other trades, inspections are required prior to the covering up of certain work. In the roofing operation, inspection must be a continuous thing to be effective; it cannot be intermittent. Each ply of felt layed and each mopping of asphalt should be inspected, otherwise only 25% of the work is visible for inspection in the completed membrane and all manner of failures could be inadvertently built in to the hidden 75%. The note which states "The roofing contractor shall not include for the roofing inspection in his tender" requires clarification. The by-laws of the A.R.C.A. require that each active contractor member accept the services of an approved independent roofing inspector assigned to him by the Association and pay for these services. Under these circumstances, it does not seem reasonable that the roofing contractor would not include for inspection in his tender. The roofing contractor might possibly arrange with his association for the waiving of the private roofing inspection if the Department of Public Works required such an inspection. It is suggested that the term "Department of Public Works Inspector", as written in the D.P.W. specifications should be more clearly defined.

7. Heading #16, relating to Guarantees makes reference to Article 18 of the General Conditions of the Contract. Article 18 requires a guarantee from the General Contractor to be effective for one year from the date of acceptance of the project. The A.R.C.A. guarantee is effective in the main, for two years from the date of completion of the built-up roof. The writers are not clear on whether or not any conflict could arise if either of these two guarantees was invoked. It is suggested that this point be clarified.

(c) A Word Regarding Roofing Pitch

In various sections of this report, the writers have recommended that specification references to pitch be deleted. This recommendation does not infer that pitch is not a suitable material for roofing. When the use

of pitch is indicated (as for a sprayed or ponded roof) it should be so specified. The fact that sprayed or ponded roof construction in Alberta is minimal led to the recommendation that pitch be deleted from the standard specification.

(d) Summary

The comments made on the A.R.C.A. and D.P.W. specifications, although lengthy, are not intended to be harsh criticisms of these two documents. Both the A.R.C.A. and this department have made significant progress towards the establishments of better roofing practices and both are to be commended for their efforts. The writers recommend that the D.P.W. specification be revised slightly. Since the D.P.W. specification refers generally to the A.R.C.A., it is suggested that the revisions be discussed with the A.R.C.A. Technical Committee prior to their adoption by this department.

IX SUMMARY OF RECOMMENDATIONS

A Asphalt

B Mineral Aggregate

C Felt

D Insulation

E Vapour Barrier

F Flashing

G Built-up Roof Construction

H Structural Decks

I Exterior Walls

J General

K Summary of Recommendations Relating to Design Criteria

A Asphalt

1. Type II (170^{o}F S.P.) asphalt to be used where type I is presently specified. The use of type I asphalt to be discontinued.

2. Minimum quantities of asphalt to be used per square:

   (a) for flat roofs (pitch not over 1" per foot)

   25 lbs. - between each ply of felt

   50 lbs. - first flood coat

   75 lbs. - second flood coat

   20 - 30 lbs. - insulation to deck or first felt ply to insulation - varies with deck material and insulation type.

   (b) for pitched roofs (pitch over 1" per foot)

   60 lbs. - one flood coat only.

3. Maximum kettle temperature to be 450^{o}F for type II

   Maximum mop temperature to be 400^{o}F for type II

Minimum mop temperature to be 375°F for type II

4. Asphalt tank or kettle to have thermometer in proper working order, to register accurately temperature $\pm 10^{\circ}$F. Kettleman to have portable stem thermometer for checking.

5. Asphalt tank or kettle to have device to assure continuous positive circulation of asphalt during heating.

6. Mechanical asphalt mopper to be used whenever possible.

7. Delete references to "coal tar pitch" from present specifications.

B <u>Mineral Surfacing Aggregate</u>

1. For flat roofs (pitch up to 1" per foot) use 500 lbs. of aggregate to be applied 200 lbs. in first layer and 300 lbs. in second layer.

2. For roofs with pitch greater than 1" per foot, use 400 lbs. of aggregate in one layer application.

3. Aggregate to be thoroughly washed, and free of dust at time of application.

4. Aggregate not to be wet, saturated or icy at time of application, but may be slightly damp.

5. When applying white aggregate surfacing, second layer only to be white.

6. Use mechanical aggregate spreader whenever possible.

7. Aggregate to be properly graded to maximum size of 5/8".

C <u>Felts</u>

1. The use of 8# glass felt to be discontinued.

2. The use of 13# and 15# glass felts to be continued, but extreme care to be exercised in closing and filling of joints in insulation.

3. All rag felts to be carefully inspected re: quality, and over or under saturated felts to be rejected.

4. Felts to be layed "two on two", whenever 4 plies of felt are specified.

5. Wet felt must not be used, and felts in place must be protected from becoming wet. If felts in place become wet unavoidably, moisture checks must be carried out prior to application of pour coat.

D Insulations

1. The following insulations to be approved for use:

   (a) Wood fiberboard, non impregnated, but factory coated with asphalt, top face.

   (b) Rigid Fiberglass, paper covered upper face and ends.

   (c) Stramit insulating Structural Roof deck, bottom face vinyl covered, and Stramit Rigid insulation.

   (d) Roofmate with top base-sheet, minimum weight 30#.

   (e) Fesco mineral board, top face coated.

   (f) Vermiculite cast-in-place insulating concrete - only if manufacturer's technical representative supervises the placing, and subsequently approves the proposed application of the roof membrane.

   (g) Polyurethane (Viking),waterproof paper covering both faces.

The following insulations appear as acceptable, but further investigation or proof of performance needed:

   (a) Rigid cork - fire treated.

   (b) Pearlite - rigid board or cast-in-place.

   (c) Foamed glass board.

   (d) Glass bead board.

   (e) Gypsum slab.

The following insulation not to be approved:

   (a) Polystyrene bead boards.

   (b) Polystyrene foams, other than Roofmate.

2. Thickness of insulation to be used is to be specified according to the following table.

3. All rigid board insulations * to be applied in <u>two layers</u>, joints of upper layer staggered with joints of lower layer. Where nailing is possible, only <u>first</u> layer to be nailed; second layer to be mopped down. Minimum number of nails to be 12 per 2' x 4' sheet.

   *Exception - 1" total thickness wood fiberboard or

equivalent, to be applied in one layer.

4. All insulations to be butt joint.

5. Treatment of joints of various insulation installations to be as follows:

   (a) Stramit insulation, Fesco board, wood fiberboard, Fiberglass and Viking polyurethane, in single layer application - tape all joints. (Single application is limited - see table).
   (b) Fesco board, wood fiberboard, Fiberglass, and Viking polyurethane in two layer application - tape all joints over 1/8" but less than 3/8" in width, in top layer only. All joints 3/8" and greater to be filled with insulation before taping.
   (c) Roofmate polystyrene - no taping required, as material is overlaid by continuous heavy asphaltic sheet.
   (d) Stramit Roof Deck in single layer application - sheet ends to be supported on metal "T" or "L" sections and all transverse and longitudinal joints to be caulked with roofing gum.

6. Insulation pieces in installations requiring taping to be layed with joints in line, both directions, to facilitate taping of the joints. This recommendation relates to the joints between insulation pieces forming each layer, whereas recommendation #3 relates to the joints of the bottom layer relative to the joints in the top layer.

7. Vermiculite cast-in-place must have firm and well-bonded surface, and be properly dried. Must be primed prior to application of membrane. Designers to pay particular attention to details when cast-in-place insulation used over concrete decks.

8. All insulations must be dry before being roofed over.

E. <u>Vapour Barrier</u>

1. Over wood deck - two plies of 15# asphalt felt with 19" overlaps - overlaps to be solid mopped. All felts to be nailed or stapled to the deck with sufficient nails or staples to resist wind uplift. This vapour barrier to be underlayed with one ply of heavy waxed kraft.

   or alternately: one ply of minimum 30# combination sheet lapped 6" and solid mopped to seal the laps. Base sheet to be nailed or stapled to the deck with sufficient nails or staples to resist wind uplift.

   Exception - vapour barrier under Roofmate is conditional.

TABLE OF RECOMMENDED THICKNESSES OF INSULATION

	"k"	C = 0.36			C = 0.24			C = 0.18			C = 0.14		
		CALC. t.	1 PLY	2 PLY	CALC. t.	1 PLY	2 PLY	CALC. t	1 PLY	2 PLY	CALC. t	1 PLY	2 PLY
1. Vermiculite concrete	0.85	2-3/8"	2-3/8"		3 1/2"	3-1/2		4-3/4"	4-3/4"		6-1/8"	6-1/8"	
2. "Stramit" roof deck	0.43												
3. "Fesco" mineral board	0.36	1	1		1 1/2"		3/4 + 3/4	2		1 + 1	2-1/2		1 + 1-1/2
4. Wood fiberboard (white)	0.36	1	1		1 1/2"	NOT RECOMMENDED	3/4 + 3/4	2	NOT RECOMMENDED	1 + 1	2-1/2	NOT RECOMMENDED	1 + 1-1/2
5. "Stramit insulation	0.33	7/8	--	NOT REQUIRED	1-3/8		--	1-7/8		--	2-3/8		2" + 1/2 WF
6. "Fiberglas" rigid	0.26	3/4	3/4		1		1/2 + 1/2	1-1/2		3/4 + 3/4	1-7/8		3/4 + 1-1/8
7. "Roofmate" polystyrene	0.20	1/2	--		7/8		--	1-1/8		--	1-3/8		3/4 + 3/4
8. "Viking" polyurethane	0.15	3/8	1/2		5/8		--	7/8		1/2 + 1/2	1-1/8		5/8 + 1/2

2. "Stramit" roof deck - this material is not included in the table, since it is a combination of both deck and insulation. Overall "U" factor for total roof system must be calculated, and compared with overall "U" factor resulting from similar calculations involving "C" values for the insulations listed.

NOTE - The dash (--) appearing in the table indicates that the material is not produced in thicknesses which would equal the calculated thickness required. This does not mean that greater total thicknesses may not be acceptable.

2. Over concrete deck - two plies of 15# asphalt felt with 19" overlap. Plies to be solid-mopped to deck and to each other.

   Exception - no vapour barrier under cast-in-place insulation.

3. Over metal deck - one ply of fire retardent film affixed using liquid adhesive with sufficient holding power and in sufficient quantity to resist wind uplift.

4. Stramit vinyl surfaced structural roof deck - no separate vapour barrier required.

5. In specific areas (see G.19 for definition) the vapour barrier is to be installed to act as a secondary membrane, sloped to secondary drains. This vapour barrier - membrane is to be glazed, but not gravelled.

F. Flashing

1. Flashing to be galvanized iron. No copper to be used.

2. For girths up to and including 12", use 26 ga. - for girths over 12", use 24 ga.

3. All joints to be either standing seam or "S" bend. Do not use simple lap joint or double seam joint.

4. Caulking to be avoided wherever possible.

5. Maximum flashing lengths to be designed to be cut from 10' length of material but preferably 8' length of material.

6. Flashings to be sloped, to allow drainage of water back to roof surface.

7. Flashing details to be worked out to utilize 30" or 36" wide sheets of metal.

8. Flashing joints to allow slippage of flashing at joint. Maximum distance between joints to be 9'-6" for "S" bend joints and 9'-9" for upstanding seams.

9. Do not attach base flashing to roof membrane.

10. Built-up roofing control joints to be minimum 10" high (measured from top of membrane) and flashings to penthouses, etc. to be minimum 10" high.

11. Discontinue the general use of soldered joints, and delete reference to soldering from specifications. Reference to soldering to be included only when specifically required.

12. Drip leg of flashings to be minimum 4½".

13. Rolled bottom edge of flashings to be connected.

14. Flashing details to be shown on the drawings, rather than described in specifications.

G. Built-Up Roof Construction

1. All decks to be inspected and approved prior to start of roofing operation.

2. Slope roof surfaces to drain. Slopes to be minimum 1/8" per ft., but 1/4" per ft. where possible. Surfaces not to be sloped toward parapet or wall, unless other slope directions are impractical. Installation of drains to take into account whether or not valleys are sloped.

3. Deck Surface to be reasonable smooth, free of ridges, bumps and hollows.

4. Deck to be dry and unfrozen prior to applying vapour barrier.

5. Edge water cutoffs to be used, at walls, parapets and all other projections.

6. Intermediate water cutoffs not to be used.

7. Insulation to be either nailed, stapled or solid mopped (first layer) and solid mopped (second layer). Do not nail second layer. Stapling of first layer is preferred over nailing. If nails used, heads to be min. 7/16" dia.; pre-punched metal or fiber washers 1" dia. minimum to be used with nails.

8. Rag felts to be layed 2 on 2, each ply solid mopped. No channel, strip or spot mopping to be permitted.

9. Roofing operation started on any one day to be completed the same day. If gravel cannot be placed same day, felts to be at least glazed to protect from sun and rain. Glazing to follow immediately behind felt laying operation.

10. Control joints to be located maximum 150 ft. apart. This spacing to be governed by shape of roof.

11. Control joints to be located to follow lines of: change of deck material, change of span of structural members, beam supporting long simple spans and lines of structural control joints.

12. Control joints to be located at areas of change of direction of roof.

13. Control joints to project minimum 10" above roof membrane level.

14. Control joints to be composed of two separate joint units, with insulation between units.

15. Structural control joints to be provided with air cutoffs, and to be insulated. Walls to be provided with air cut-offs at roof level.

16. Flashings to project through parapet under masonry copings, (when masonry copings are used) and to run over cant strips and up entire inside face of all parapets.

17. Base flashings not to be mopped into roof membrane - turned edge of flashing to rest firmly on gravel surface. Any water penetrating cap flashings must be allowed to escape and drain <u>onto</u> the roofing.

18. Under all cap flashings, built-up membrane or coated base sheet to be located and attached to parapet or other projection being protected.

19. On low roof construction (next to tower or around pent-house) temporary roof to be installed, sloped to drains installed at this deck level. When all work on tower or higher portion of building is complete, roofing to be finished by placing insulation and membrane. Second set of roof drains to be set at this higher membrane level.

20. Controlled flow roof drains <u>not</u> to be used.

21. All vents and other piping projections through roof are not to be anchored to either the roof deck or the roofing. Pipe must be free to move in gum filled collar.

22. Roofing at temperatures below zero to be avoided. If air temperature is below zero, protective hoarding to be erected, and heating of enclosed space to be carried out.

23. Rigid inspection during construction to be carried out. The inspector should be retained by the owner, and report to the owner if inspection is to be effective.

24. Roof inspection by owner to be carried out twice yearly-to check drains, flashings, gravel, surfacing, ponding and condition of asphalt.

H. Structural Decks

1. Precast concrete elements to be joined together to eliminate differential deflections.

2. Differences in elevation between adjoining elements to be feathered out, minimum 1" in 48".

3. All concrete decks to be primed prior to application of built-up roof.

4. Metal deck elements to be positively joined together and supported to eliminate differential deflections.

5. Fir plywood ½" thick to be affixed to metal deck if the deck area to be used as a working platform.

6. Sheathing for wood decks to be maximum 8" wide boards.

7. Asphalt, or asphalt impregnated or coated materials not to be applied directly to wood deck.

8. All decks to be sloped to drain, preferably ¼" per foot minimum.

I. Exterior Walls

1. All exterior walls to have vapour barrier installed on inside face, from suspended ceiling to underside of floor above.

J. General

1. Sincere effort be made by D.P.W. to have designers spend time in the field.

2. Further thought be given to the construction of a roof membrane made up of a combination of glass felts and rag felts, and a small project be roofed as a trial using this type of membrane.

3. Further thought be given to the insulation -over-membrane concept, and a small project be roofed as a trail using this system.

4. Further thought be given to intermittent bonding of vapour barrier to deck, and membrane to insulation through the use of a perforated base sheet, and a small project be roofed as a trial using this type of base sheet.

5. Further thought be given to the incorporation of high tensile glass fabric into built-up roof systems, and a small project be roofed as a trial using this material.

K. Summary of Recommendations Relating to Design Criteria

Many of the recommendations so far outlined in this report merely reiterate the principles of good roofing practice with regard to materials and workmanship. Some of the recommendations, however, suggest a change from what are generally accepted design standards.

It is no longer necessary to make a recommendation which might have been put forth a year or so ago. This recommendation concerns the upgrading of the roofing trade.

The Alberta Roofing Contractors Association has been a prime mover in organizing an apprenticeship training course in Alberta. The program has the backing of the Labour Union and is now being handled principally by the Alberta Government Apprenticeship Board.

The apprenticeship training course consists of a four-week period of instruction at either N.A.I.T or S.A.I.T., and a three-year apprenticeship in the roofing trade. The first classes were held in January of 1966. The effects of the training program will not be felt in the construction industry for possibly another five years. Tradesmen having completed their apprenticeship, it is hoped, will gain recognition and should command higher wages. Through recognition and higher wages, it is expected that workmanship within the roofing trade will improve considerably.

The principle recommendations which will effect design changes are:

1. Roofs must be designed to eliminate standing water. All roof surfaces and flashings must be sloped.

2. Flashing areas should be increased. The use of caulking or soldering to render flashings watertight must be discontinued, except where other means are impractical.

3. Quantities of asphalt must be substantially increased from the present 20# or less between felts to 25# on all roofs and from 60# or less on the flood coat to 125# on roofs pitched less than 1" per foot.

4. Higher softening point asphalts must be used for flat roofs - change from type I to type II·

5. A temporary roof must be constructed in any roof area wherever construction is to be carried out adjacent to or above this area.

6. Air cutoffs must be installed to prevent influx of humid air from walls and building control joints, into the built-up roof system.

In conclusion, the writers feel that perhaps all of the recommendations presented in this report can be generally summarized as relating to design and workmanship.

It is evident from the study carried out preparatory to the writing of this report, that designers must review the basic laws of physics. Designers should be required to spend time in the field in order to become familiar with roofing operations. Designers should become more familiar with the practical limitations of materials used in built-up roofs. It is a bit unreasonable to expect a conscientious tradesman to do first-class work if he has to do it on a detail so poorly designed it could never perform properly. A knowledge and appreciation of both manufacturers and tradesmen's problems is essential if good design is to be produced. Designers must also become more critical when giving approvals to new or substitute materials. A knowledge of the alternate must be gained before approval is given.

Workmanship must compliment design. No matter how good may be the design of a built-up roof and no matter how good the materials used in its construction, the completed roof can be no better than the workmanship used to assemble the materials.

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APPENDIX A

PHOTOGRAPHS

1. Improper storage of materials. Felt rolls should not be stored flat. Note rolls stacked in the mud. This type of storage promotes fishmouthing and excess moisture content.

2. Unprotected insulation - bundle wrappings broken-no pallet to keep material out of the mud, and no protective covering over stacks.

3. Unprotected insulation.

3A Improper storage of insulation.

4. Unprotected wood fibre cant strips.

5. Preferable method of supplying asphalt to the work area - tank has circulating pump with bypass valve controlled by pull rope.

6. Preferable method of supplying asphalt to the work area.

7. Asphalt being discharged directly into applicator.

8. Trafficway for entire roofing operation - insulation and felts badly damaged.

9. The low roof will probably be damaged during construction of adjoining high building.

10. Low roof adjacent to tower.

11. Low roof adjacent to high part of building.

12. Low roof adjacent to tower.

13. Low roof adjacent to tower.

14. Low roof adjacent to tower.

15. Low roof adjacent to tower.

16. Low roof adjacent to tower.

17. Mechanical damage to completed membrane.

18. Probable mechanical damage to completed membrane.

19. Water soaking into unprotected rag felts.

20. Sudden rainstorm - no chance to protect felts from getting wet.

21. Fibre cant strips mopped when wet - note frothy asphalt lower lefthand corner.

22. Proper palletizing of materials, however, note primer being applied over wet area of concrete deck.

23. Split felt - should have been lifted and lapped properly.

24. Fishmouthing - results from poor roll or poor rolling.

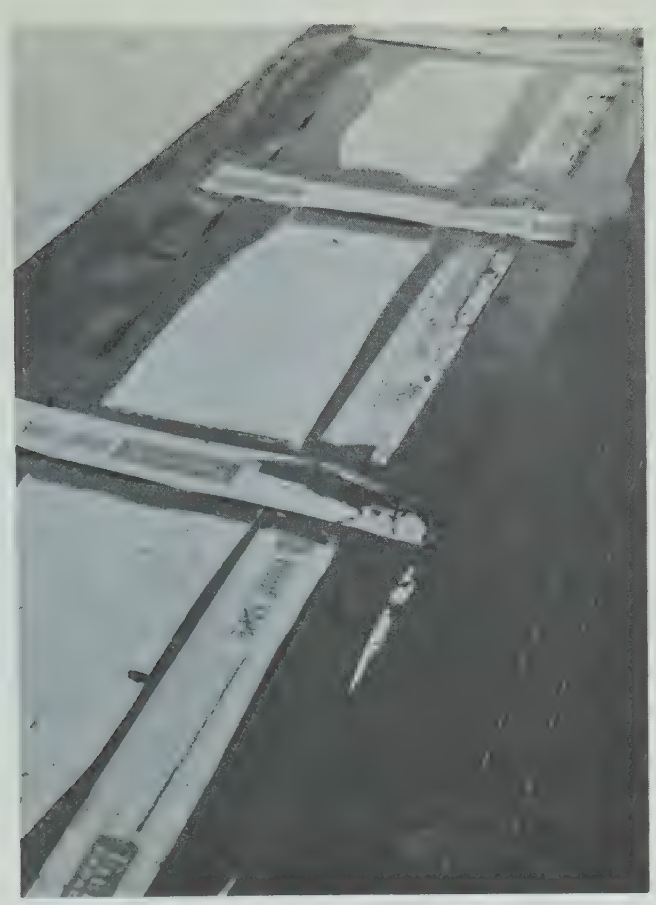
25. Fishmouthing and curled edges - unprotected felts.

26. Severe fishmouth - unprotected felts. On some types of insulation, the loose stones will penetrate the membrane if stepped on.

27. Application of hot asphalt using mechanical applicator (mini-mopper).

28. Rolling out the felt - kicking not recommended. Note puddle running ahead of roll - this puddle lessens considerably as roll lessens in weight.

29. Toward end of roll - no puddle.



30. Taping of insulation joints - this taping job may well produce more problems than no taping at all.

31. Installation of cut-off - The resulting rounded edge may well cause more problems than the cut-off is intended to eliminate.

32. Installation procedure precludes installation of edge cut-off. Edge cut-offs are a must.

33. Proper rolling procedure - note puddle running ahead of roll, and use of broom. This membrane is being installed 2 + 2.

34. Over-saturated felts - note sheen on surface. Roll was difficult to keep straight.

35. Severe fishmouthing resulting from poor felt rolls - a 2 + 2 application will reduce appreciably the possible failure of this area.

36. Uniform application of gravel through use of mechanical gravel spreader.

37. Roof gravelled using spreader.

38. Gravel blown from membrane - asphalt left exposed to the sun and precipitation.

39. Asphalt exposed when gravel blown away.

40. Finished membrane protected, however, unless wheelbarrow is handled with care, membrane could be ripped.

40A Proper protection for ladder feet - very often overlooked.

41. Protection of membrane at materials handling area.

42. Curbs readied for flashing.

43. Curbs completed, and equipment in place.

44. Gumpot installation properly installed around pipe anchor.

45. Proper return of felt over facia, however, note lack of control joints in membrane at changes of roof direction.

46. Proper protection of wood deck awaiting application of roofing.

47. Nailing pattern - felts nailed to wood deck with 7/16" diameter headed roofing nails at approximately 12" o.c.

48. Roof-mate does not melt under bucket of asphalt at 400° F. Rings are asphalt drip.

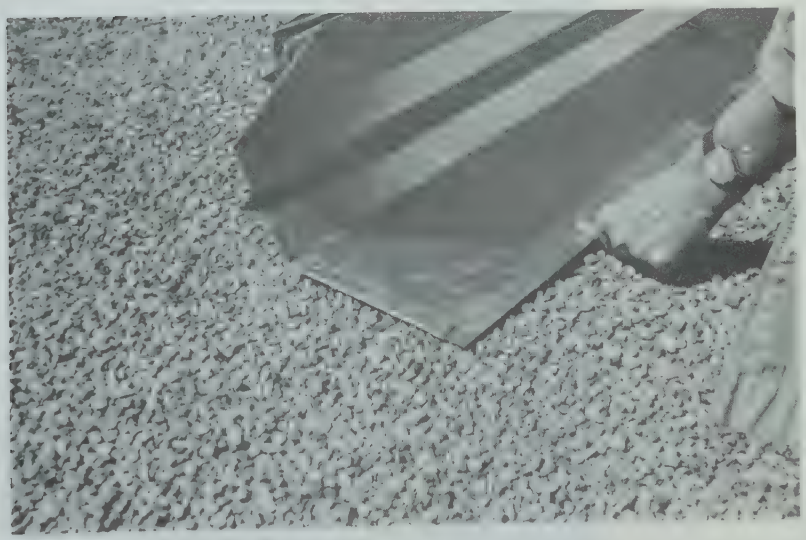
49. Gravel should not be stored on roof, but should be raised to roof only as required.

50. Application of 60# N.I.S. (19 inch selvege, mineral surfaced). Better to apply in direction of slope than to apply horizontally. Horizontal application usually results in "waving".

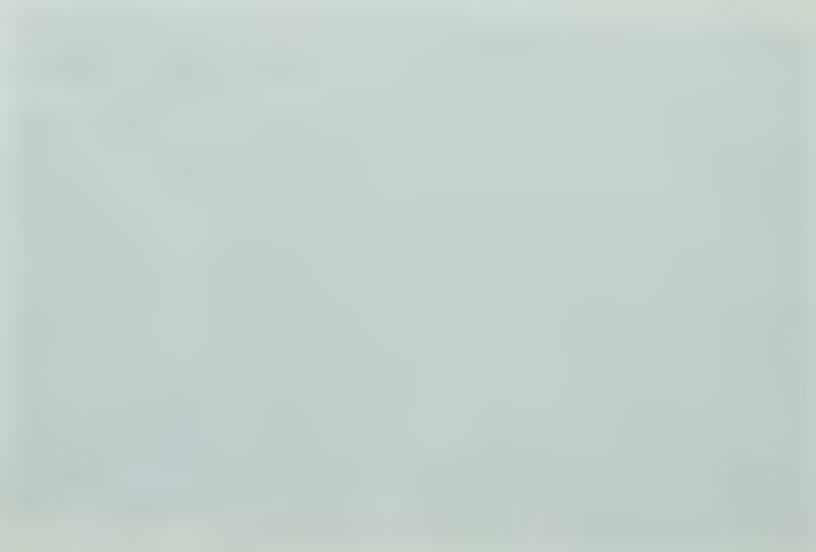
51. One 2 x 4 dropped, and the roof leaks!

52. Roof drain - screen does not prevent gravel from being washed into drain, resulting in possible plugged line.

53. Most paints crack when exposed to sunlight. The crack in a 2 mil film of paint is a sufficient stress raiser to cause a deep fissure in the asphalt, as happened in this test.

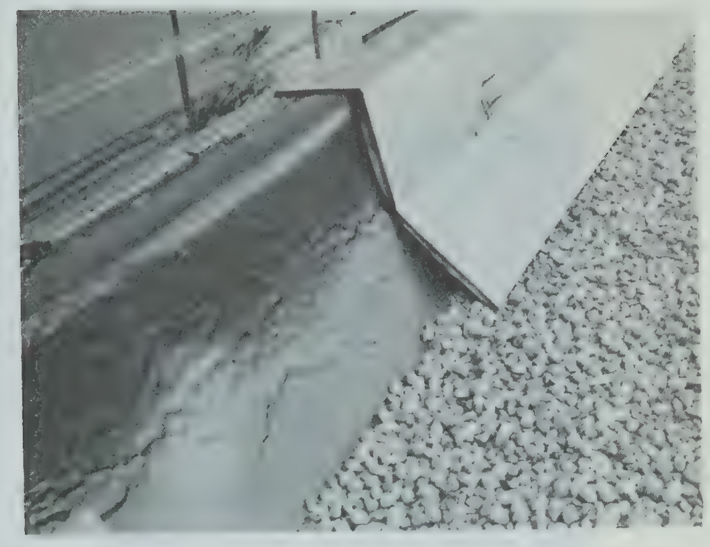


54. Flashing joint - Good and bad details - double "S" bend in 26 ga. galvanized iron is good. This joint should be improved by the extension of the upper face of the bend to allow proper anchorage. The length of the bend should be at least 2". No provision for continuity of lower edge.

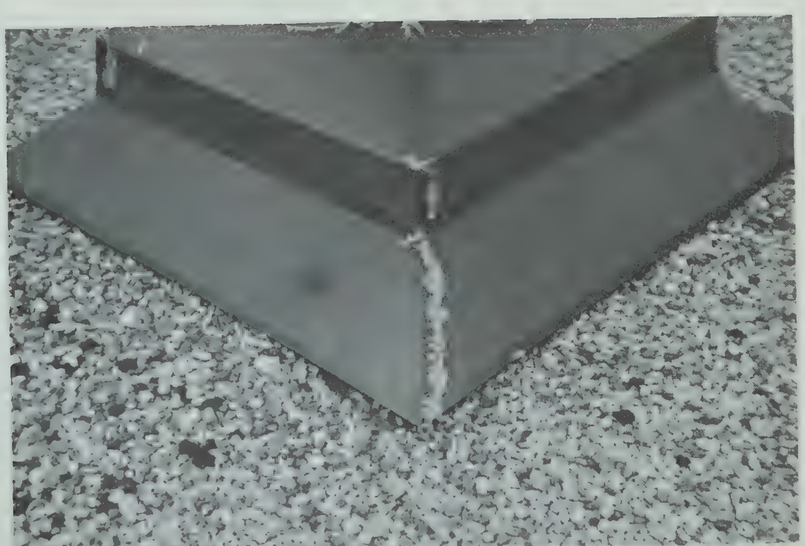


55. Good flashing detail - note absence of exterior caulking, and slope of top surface.

56. Flashings properly kept free of membrane.



56A Note gravel run under flashing - proper installation.

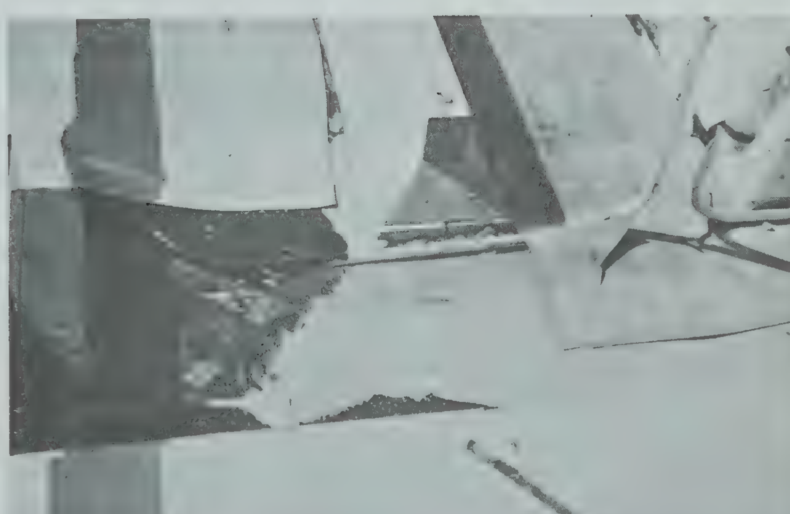


57. Note break in lip of flashing - this break stiffens the edge against wind uplift, and is most effective in long stretches of flashing.

58. Note 10" high control joint - this detail should be no less than 10" in height. Note also exposed face of parapet wall - this wall should be protected.

59. Metal deck not properly supported at opening. Weight of man depressed deck 3/4" - if not properly supported before membrane applied, could result in split.

60. Installing base sheet vapour barrier over conduit - unsatisfactory application, and open invitation to trouble. (Roofer has no choice here - only the designer could alter this situation).



61. Installing Base Sheet vapour barrier over conduit which is tight to the deck - poor.

62. Application of Roof-Mate foamed compressed polystyrene rigid insulation directly to wood deck.

63. $1\frac{1}{4}$" Roof-mate being nailed to $\frac{3}{4}$" wood deck - 8 roofing nails per sheet. Note discontinuity of roof deck and uneven top of concrete wall. No joint in the roofing was provided here. No vapour barrier used, according to Roof-Mate specifications.

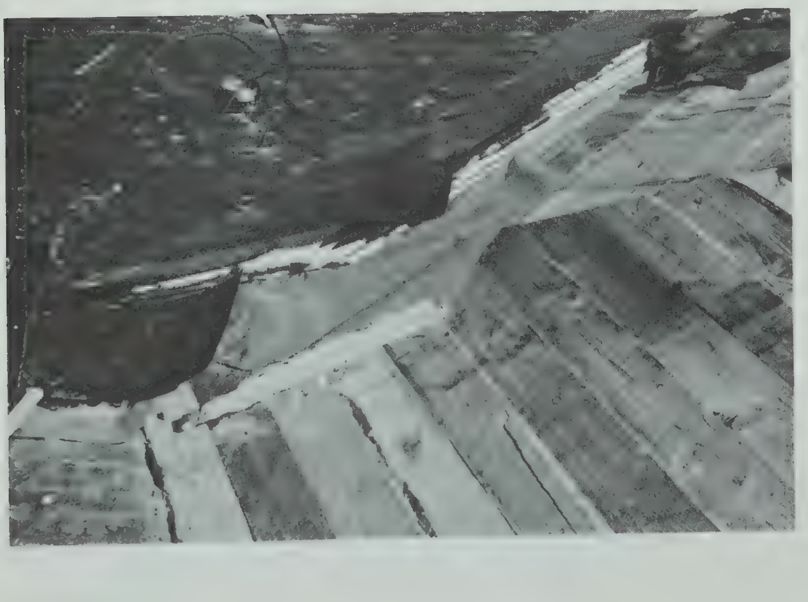
64. Joints in insulation exceed $\frac{1}{4}$" in width - note pencil as reference.

65. Joints being plugged - up until membrane was ready for application. Joints not plugged by then, were left.

66. Open joints in wood fibreboard insulation. Ship lap material manufactured off square - roofer preferred two layer staggered butt joint application, rather than one layer shiplap joint.

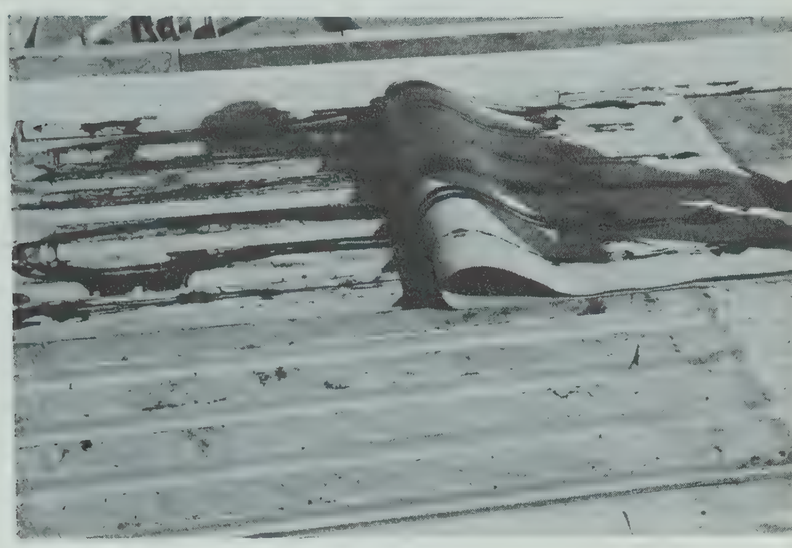
67. Routing out of insulation to fit over conduit. Note the fit of the base sheet V.B and the insulation in place. Avoid conduit on top of deck if at all possible. Three quarter inch thickness of insulation is insufficient thickness to control condensation in conduit.

68. Felt run up parapet, Loose fit to cant strip and parapet contour is source of trouble in completed roof.

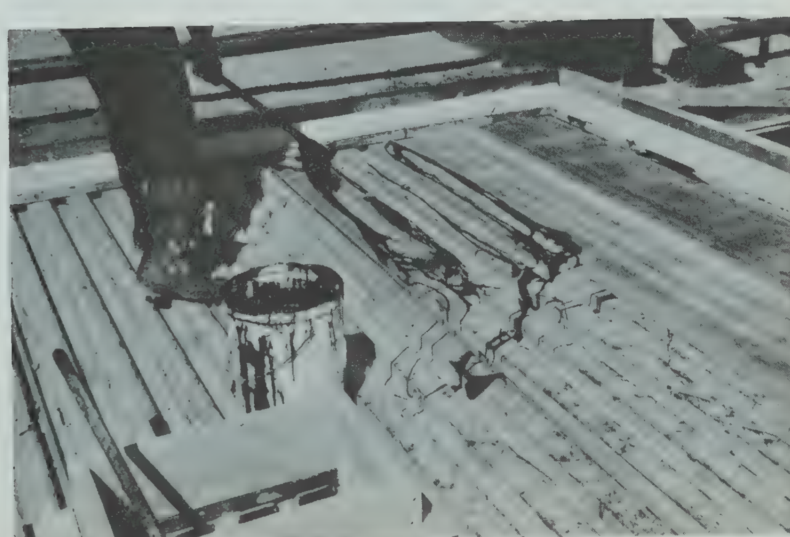


69. Loose fit of insulation at change in roof contour. Photo shows wood deck, single x waxed kraft, 2" wood fibreboard and 4 ply 15# rag felt.

70. Close-up of above photo, showing $\frac{3}{4}$" gap between insulation and deck. Gap is about 10" wide.

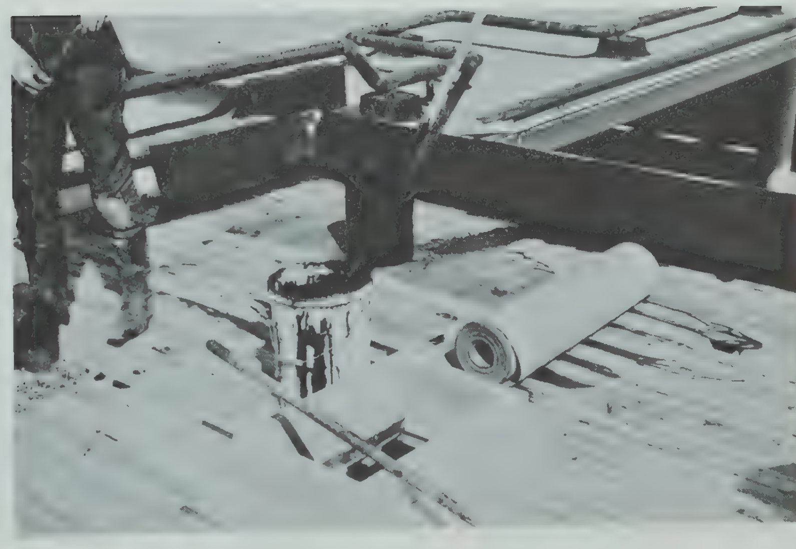


71. Cold adhesive applied, and 30# glass base sheet placed.



72. Application of cold adhesive for placing of second strip of base sheet. Extreme care required when walking over base sheet.

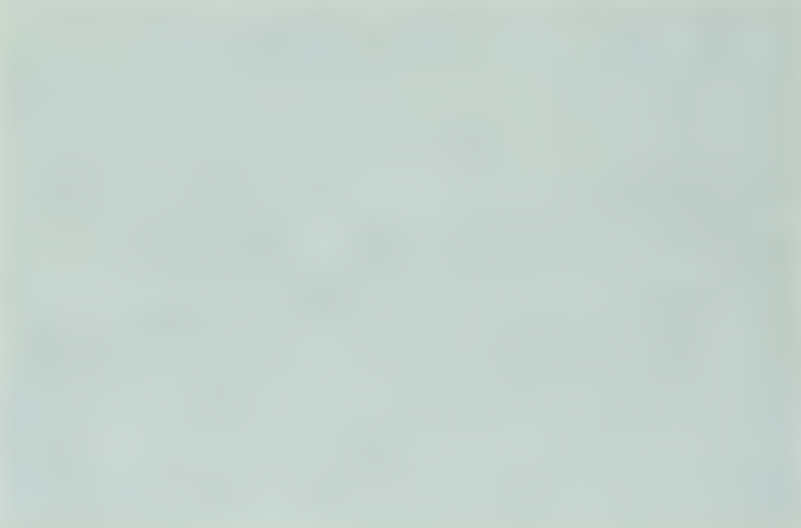
73. Rolling out second strip of base sheet.



74. Placing of edge cut-off strips in maximum 8' lengths (strips 18" wide). Strips mopped in hot asphalt.

75. Laying of first width of insulation next to cant strip. Insulation placed in hot asphalt mopped over cutoff strip and base sheet.

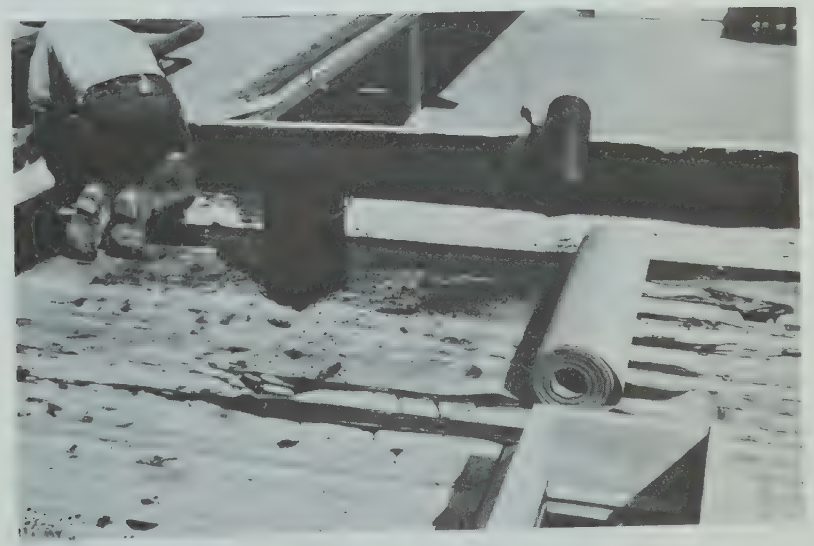
76. Insulation ready for turning back of edge cutoff.



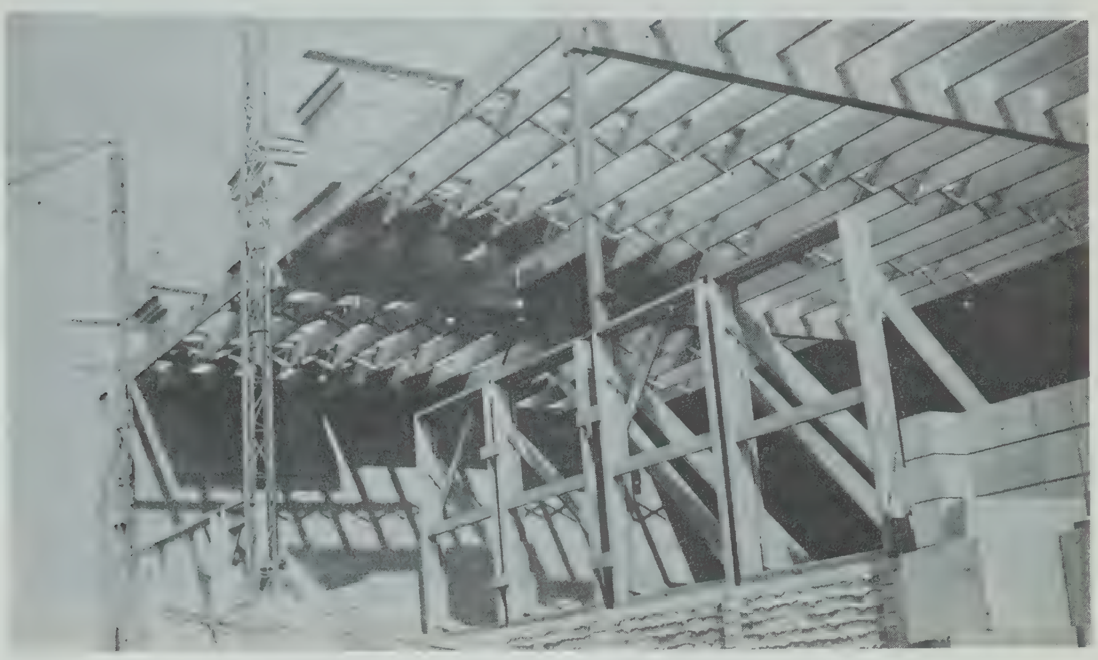
77. Mopping to seal edge cutoff.

78. Pressing edge cutoff strip in place.

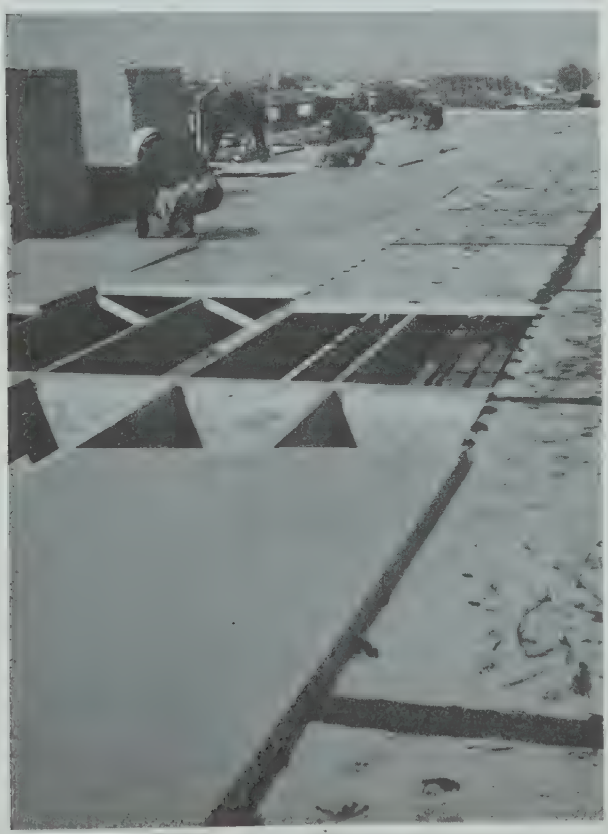
79. Mopping over edge cutoff and up cant strip - ready to receive starter strip of 15# rag felt.



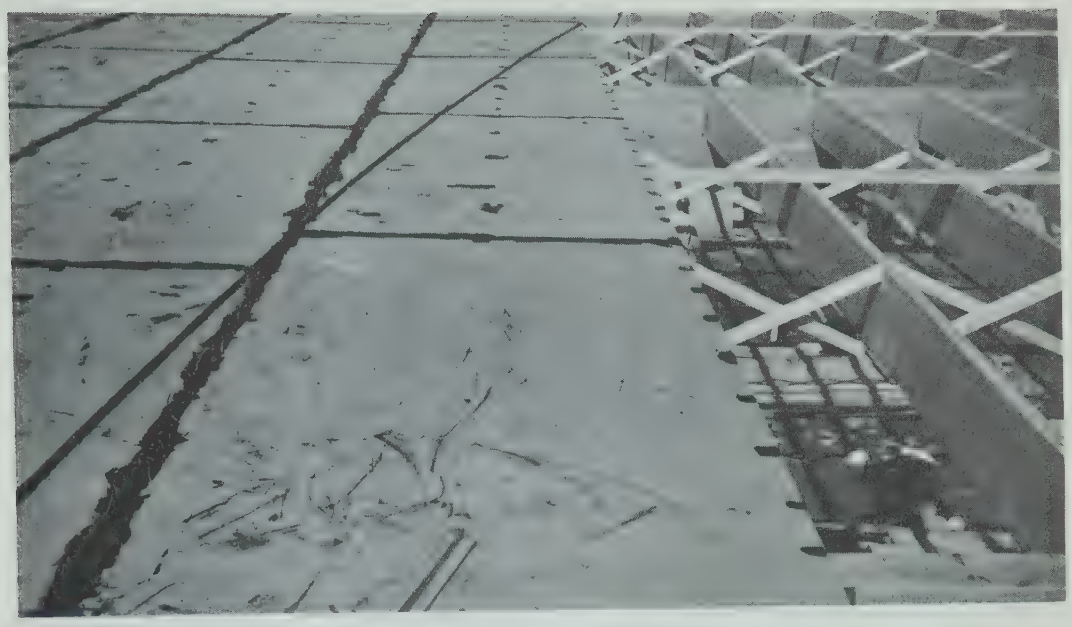
80. Pressing in place of starter strip - (one slip of the boot and a hole is made in the base sheet!). The workmanship on this job was far above average.



81. Stramit Structural insulating deck ready for placing on warehouse roof. This insulation was left unprotected over at least one weekend.



82. Stramit being nailed to joists at 2 ft. o.c. $3\frac{1}{2}$" coated nails at 10" o.c. placed along edges.



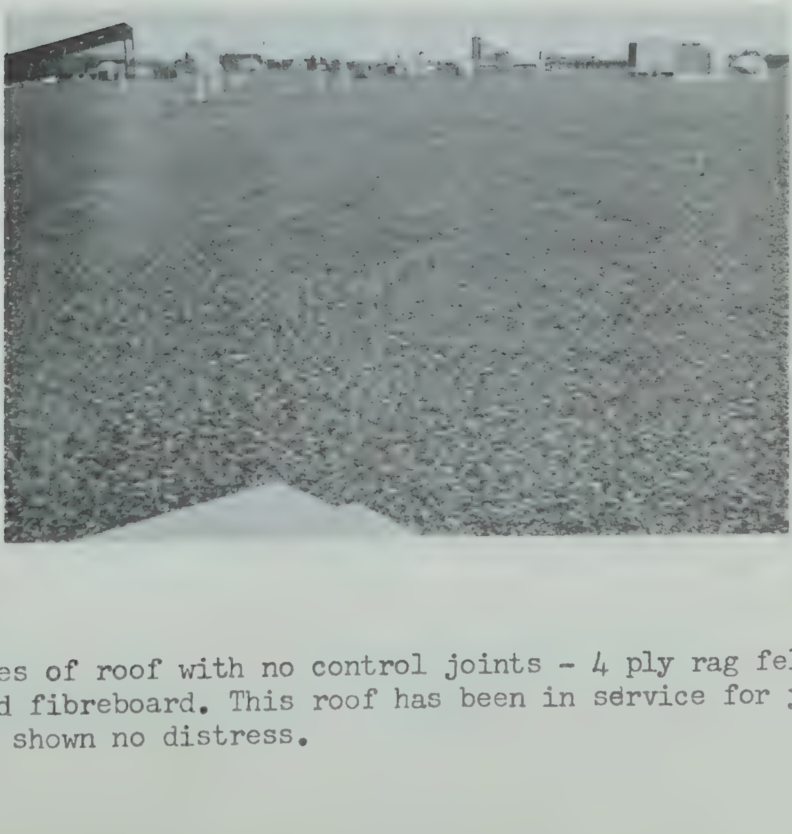
83. Stramit deck with joints gum caulked and nail heads gummed. Gum assures continuous asphalt coating of underside of first ply of felt.

84. Side joints are tight, but end joints are open occasionally. Metal tee below joint prevents caulking gum from sagging out of joint, and gum prevents moisture from pentrating to underside of membrane. Tee also supports Stramit and eliminates differential deflection between adjoining sheets.

85. End "ell" for support of end of Stramit. Note that cant strip is nailed to joists, and not placed over Stramit.

86. Underside of Stramit deck - this installation used exposed paper type board on soffit - a few cents cheaper, but unwise if humidity on interior is above normal.

87. Underside of Stramit deck - vinyl covered sheets used in this installation.



88. Acres of roof with no control joints - 4 ply rag felt on wood fibreboard. This roof has been in service for years, and has shown no distress.

89. Roof membrane suffering from extensive blistering. This roof membrane has been rising and falling for some years now, but as yet has not leaked. It won't be long, however - the gravel has been blown from the tops of the blisters, and the glass fibres in the felts are becoming exposed. Note the water, and location of drains.

90. Button punching at close centers (max. 2' - 6") is essential to prevent differential deflection of metal deck sections.

91. Photo taken looking up wall of Foothills Hospital - a visual reminder that this same ice buildup, resulting from moist air escaping onto a cold surface, can occur under a roof membrane, and cause delamination and rupture . (Dec. 1966 - outdoor temperature - 5^{o} F.). This escape of air is more pronounced in tall buildings due to stack effects.

92. Roof vent (one per 1000 sq. ft. of deck) as recommended for installation over Zonolite insulating concrete deck. The picture also shows that gravel was prematurely stored on the roof.

93. Surface of Zonolite topping prior to priming. This material is an insulating lightweight "concrete".

94. Patching of spalled areas of Zonolite insulation. Spalling was result of light frost after placing.

95. Vapour pressure relief hole - 6" dia.

96. Priming of Zonolite deck with cold asphaltic primer.

97. Laying of rag felt "wicks" in sprinkle mopping.

98. Sprinkle mopping - continuous vapour paths intended are not in evidence.

99. Channel mopping - it is doubtful if this application performs as intended. Single ply 15# rag flet is being applied over primed and "wicked" deck.

100. The day after roof was completed - note large blisters
in membrane.

101. Blister in membrane.

102. Completed roof. Gravel should not be stockpiled on roof. Note only a small portion of membrane has been glazed to protect from moisture and sun-curling.

103. Sun-curling of unprotected felts left exposed for several days. This condition may or may not result in future problems, but general opinion is that this condition should not be allowed to develop.

104. Pierced blister - note absense of asphalt bond to substrate.

105. Pierced blister of membrane layed over Zonolite deck. Note the top surface of the Zonolite adhering to the asphalt. What is holding this membrane down in hot weather, other than the weight of the membrane, pour coat and gravel? (approx. 7 psf).

106. Removal of wet wood fibreboard insulation from Museum and Archives Building, low North roof.

107. Replacement of wood fibreboard insulation - approximately 250 squares were replaced at a cost of about $20,000, according to the contractor. This replacement was necessitated by mechanical damage to membrane which occurred during construction of the building.

108. Re-laying of 3 ply glass felt membrane over replaced insulation.

109. Reseating of flashings - without complete removal of flashings, and reinstallation after completion of reroofing, this is the only way the bent up flashings can be held down. Note wheel-barrow full of gravel parked on unprotected membrane.

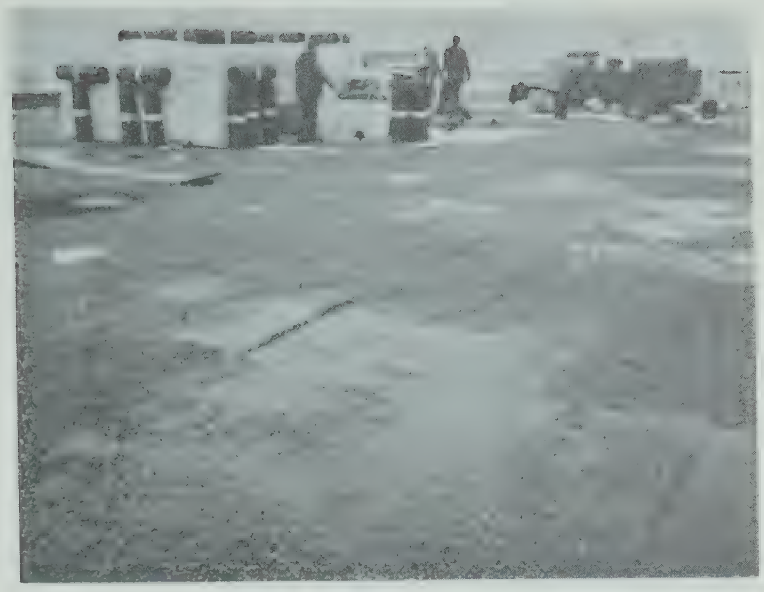
110. Gravelling in of sprung - in-place flashing. This is not generally considered good flashing practice, but notice the stonework which would have to be removed in order to do the job properly.

111. Flashings over control joints after reroofing completed. Flashing to the right does not project high enough above roof surface. Wind-whipped water will find a leak if there is a weak spot.

112. No slope to drain on this roof. Ponded water will cause accelerated deterioration of asphalt. In spring and fall, (also in winter, if insulation has lost the most of its insulating value) alternate freezing and thawing of water may damage a membrane severely by accelerating splits.

113. March 20, 1967 - "A" Block - pattern of joints in insulation clearly visible to the eye (pencilled in on photo).

114. March 20, 1967 - "B" Block - Patch cut out of membrane reveals uncaulked joint in Stramit insulation. Gap is 3/8" wide.



115. Below freezing weather, but water standing on the roof. Note ridging of membrane at end joints of insulation.

116. Note sagging of membrane at edge joints of insulation, as shown by water pattern.

117. Joint in flashing is only ½" simple lap, with exterior caulked. Note snow standing level with top of parapet. Top surface of flashings has no slope to permit water run-off.

118. Snow above level of, and covering portions of parapet shown in above photo.

119. Snow melted through action of warm air escaping from building interior.

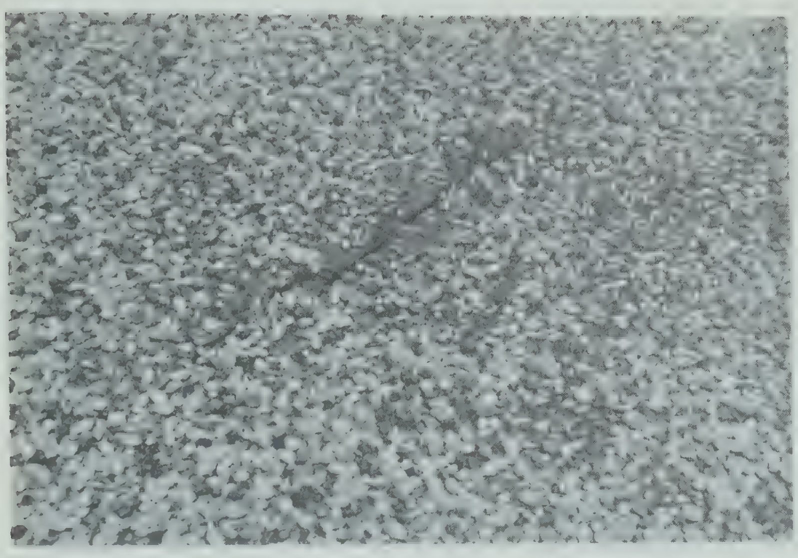
120. Graphic illustration of escape of warm air from building interior. Note exterior caulking has become brittle and cracked.

121. Removal of completely saturated Stramit - a very messy job. March 28th, 1967 - "C" Block.

122. Removal of soaked Stramit - note water standing on the deck. Needless to say, water was running through the ceiling below. The water leaked into the insulation through faulty flashings. No splits or holes were found in the membrane.

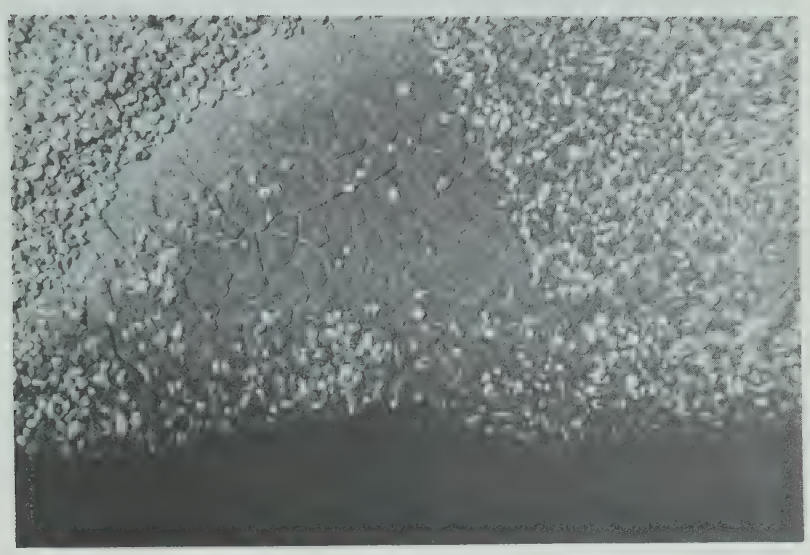
123. Low pitched roofs of "H" unit and Lodge. Roof construction is Structural Stramit over wood joists. Membrane is 3 ply of 8# glass felt.

124. Split in membrane. Splits like this are difficult to find.

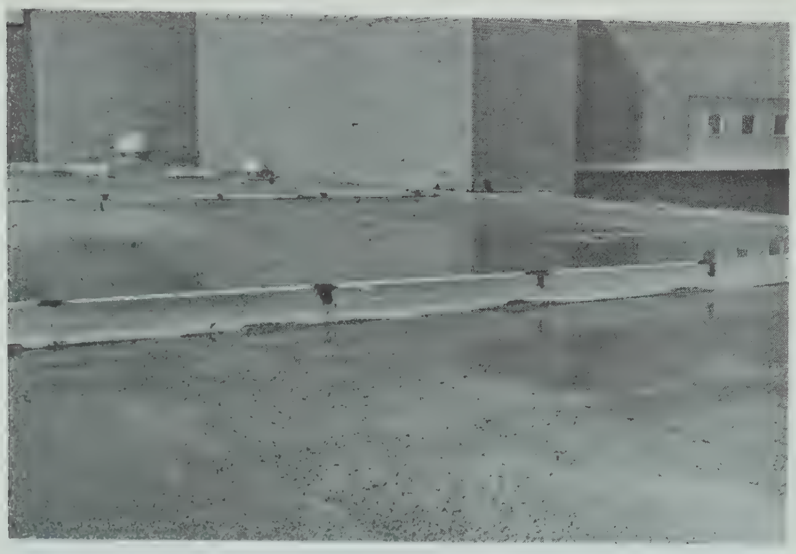


125. Split in membrane.

126. Poor gravel stop installation - end of metal strip was not properly contoured to the deck, and the sharp end has worked itself through the membrane. The resulting hole in the membrane resulted in a leak, and ruin of this area of the roof.



127. Lack of asphalt on the flood coat resulting in wind blowing away the gravel. Note the crazed asphalt - cracks penetrate to the glass fibres of the felts.



128. Reroofed and reflashed area (1966/67) - note caulked joints in flashing. Top of flashing is sloped to center, forming a trough to catch water. Already this caulking is peeling off of the metal. Note also the ponds of water, and roof drains high and dry.

129. Reroofed area - dry roof drain and ponds of water laying up against flashings.

130. Reroofed area - serious water ponding against gymnasium wall flashing. This area was done by a roofing contractor. Note the dip of surface, as defined by line of water.

131. Reroofed area (fall 1966) done by D.P.W. crews. Neat job well done. Foreground shows contractor reroofing job. This area was flashed using standing seams.

132. Looking north - all areas shown have been reroofed with Stramit and rag felts. Note insulation joint pattern visible. Pour coat and gravelling skimpy here. All areas south of the main entrance, and all wings have been reroofed with wood fibreboard and rag felts. All reroofed areas now incorporate a vapour barrier.

133. Top of cap flashing slopes properly to shed water, and drops $4\frac{1}{2}$" over base flashing. Seams are "S" bend. Note, however, that base flashing has been anchored to the membrane. This procedure is not generally considered good. The parapet and flashing should be free to move independently of the membrane.

134. Flashing which was installed less than one year ago. Caulking has cracked. Note pond on far side of control joint. A leak here is iminent unless this is repaired. If it leaks, how much insulation will become soaked?

135. Roof membrane control joint - installed only last year during reroofing. There were no joints in this roof initially. Note the 8" difference in elevation between surfaces (drops left to right). The original detail here was simply a strip of 60# mineral coated selvege mopped onto the membrane felts.

136. Control joint runs up through foundation, main floor slab and topping, plaster block and brick walls, but does not continue through the roof structure or parapet. The entire 900 ft. long by 60 foot wide roof structure is in one continuous piece. Note the joint in the brick above the window was overlooked - the brickwork formed its own joint, however.

137. Control joint in basement wall and main floor slab.

138. Vapour pressure relief vent installed as precaution. The original roof design of the School for the Deaf called for a vapour barrier, however, this was deleted by D.P.W. request. The open type T- bar and egg-crate ceilings, along with the precast double Tee deck offered no resistance to the penetration of moisture into the insulation.

139. Phase I roof - note water standing remote from drain. The reflashing here illustrates proper depth of drip-leg.

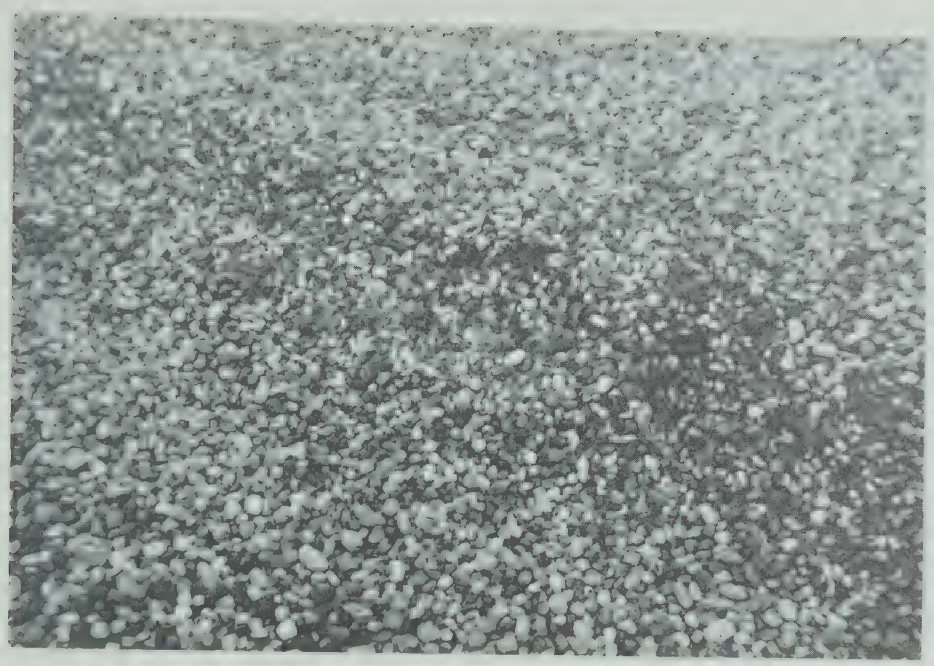
140. Phase II Library & Auditorium roof - note water standing remote from drain. The flashing seen is all new.

141. Illustration of continuing building movement - paint has flaked from the metal. Original detail had joint caulked, with small strip of flashing over top of beam at joint. Metal strip has been applied over joint, entire top has been flashed, and counter flashing has been reset into reglet.

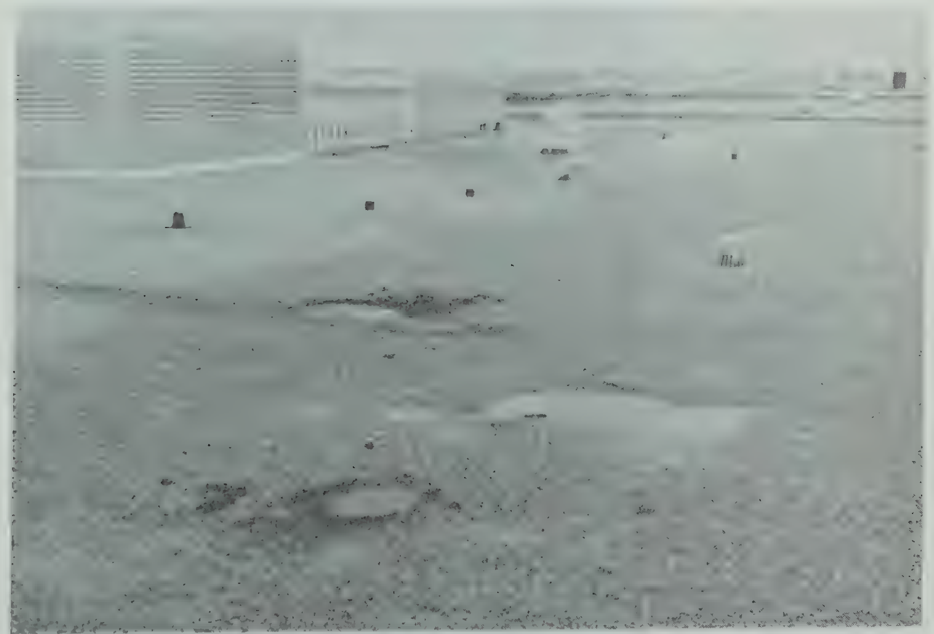
142. Phase III original copper flashings - note water retained.

143. Phase III original copper flashing - note water lying against cracked caulking - drip leg of cap should be min. $4\frac{1}{2}$", but is only just over 1".

144. Phase III Medical Wing - 5" change in roof elevation should have had metal gravel stop and cant base flashing - repairs are in progress.



145. Phase III Medical Wing - the reason for the repairs. Note deep fissure in asphalt. This crack extends through the membrane. Picture is close-up of lower R.H. corner of photo #144.



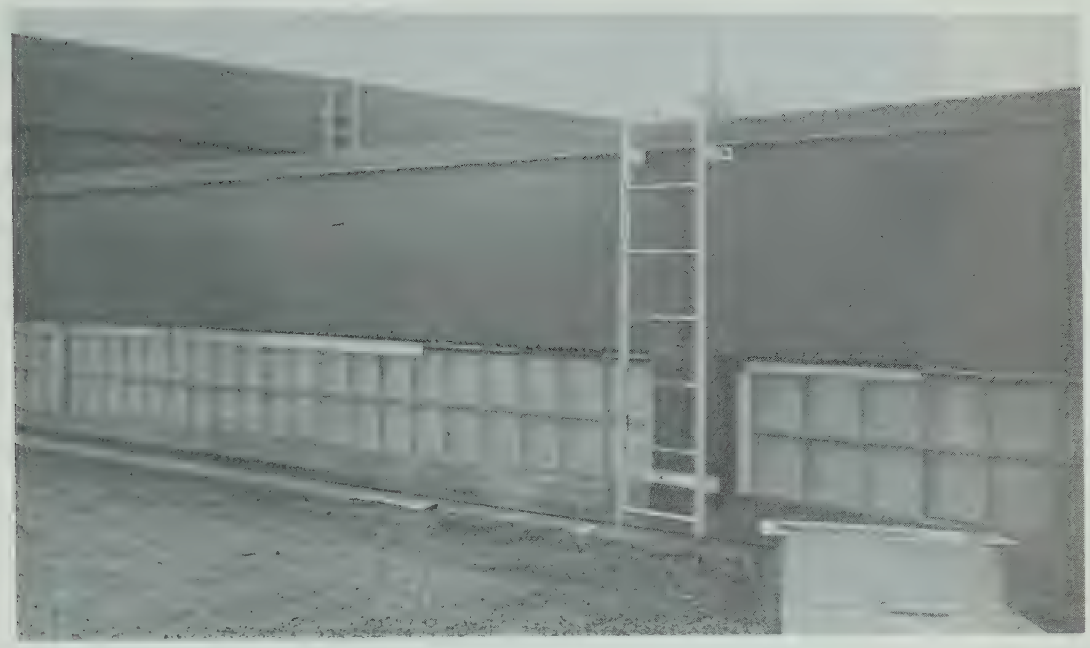
146. Phase III Technical Block. Temporary repairs to splits in membrane are in progress. Drains to the left of the picture are original - drains to the right had to be installed about two years ago to control ponding over the building control joints.

147. Phase I - mitered corner in flashing was originally soldered. The soldered joint broke apart, and now the caulking has ruptured.

148. Reinstallation of original control joint (see Fig. #20) showing properly sloped top.

149. Newly installed bases for wooden platform (see fig. #19). Original platform rested on sleepers layed directly on membrane - leaks developed after membrane split.

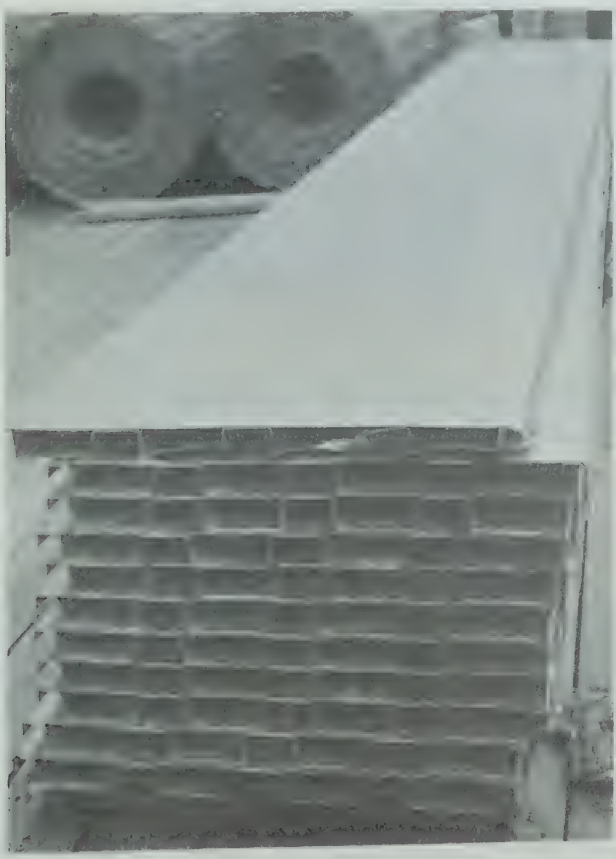
150. Reflashing - typical for entire building. Original detail was as shown in fig. #19.



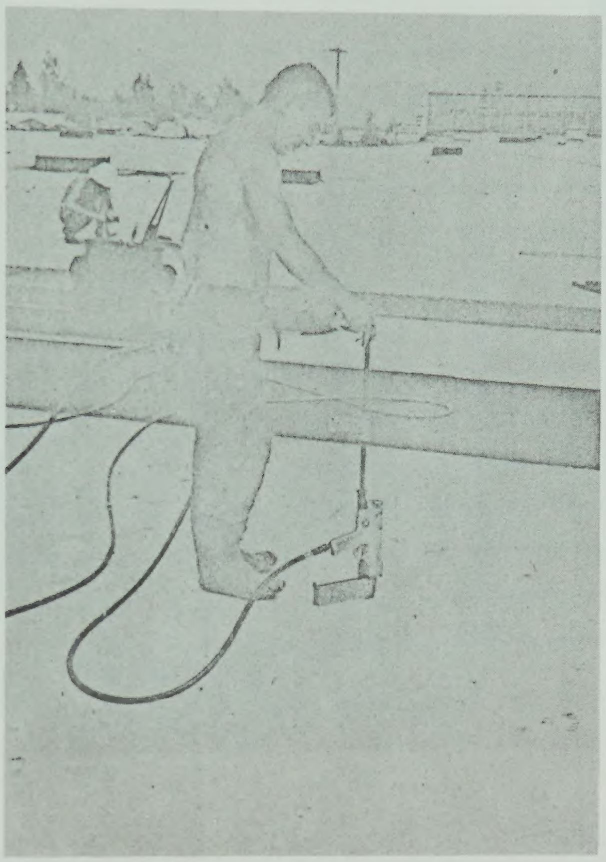
151. Reinstallation of cracked glass block has been completed. Flashings now are having to be introduced to prevent leakage. Original detail had no flashing.

152. Flashings were blown loose, and are now being removed and repaired. The cap flashing was simply crimped and set into brick mortar joint. Flashings sloped toward wall.

153. Close-up of photo #152. Note severely corroded copper. Mortar "caulking" is loose. Water stain on brick indicates water has been long standing on the cap flashing.



154. Metal deck - this type when installed produces flat roof deck surface rather than fluted.



Stapling gun used to install rigid
insulation to wood deck.